U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-252 703

INVESTIGATION OF ACID MINE DRAINAGE EFFECTS ON RESERVOIR FISHERY POPULATIONS

WEST VIRGINIA UNIVERSITY

PREPARED FOR
INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY

APRIL 1976

139194

PB 252 703

EPA-600/2-76-107
April 1976

INVESTIGATION OF ACID MINE DRAINAGE EFFECTS ON RESERVOIR FISHERY POPULATIONS

by

Arnold Benson
West Virginia University
Morgantown, West Virginia 26506

Contract No. 14-16-0005-3034

Project Officer

Ronald D. Hill
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. D COMMERCE

145

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-76/107

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
INVESTIGATION OF ACID MINE DRAINAGE EFFECTS ON RESERVOIR FISHERY POPULATIONS

5. REPORT DATE
April 1976

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Arnold Benson

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
West Virginia University
Morgantown, West Virginia 26506

10. PROGRAM ELEMENT NO.
1BB040

11. CONTRACT/GRANT NO.
14-16-0005-3034

12. SPONSORING AGENCY NAME AND ADDRESS
Bureau of Sports Fisheries & Wildlife
Dept. of Interior, Washington, D.C.
And
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final, 1966-1967

14. SPONSORING AGENCY CODE
EPA-ORD

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A limnological, water quality and quantity and lake fluction, transparency, and ice cover study was made of the Tygart Lake, West Virginia, and its tributaries. The watershed of this lake has been extensively mined for coal and acid mine drainage (AMD) is discharged throughout the area. The significant sources of AMD were found to be the Tygart River and Sandy Creek. Net changes in lake depth were 14-16 meters, and the maximum change 22 meters. Transparency depth ranged from 0.1 m in December to 7.5 m in the summer. The major factors related to the development of acidity grandients in Tygart Lake were found to be (1) hydrological characteristics including inflow, outflow, and the operational interaction between the inflow and outflow resulting in storage or drawdown, (2) thermal relationships including the spring warming cycle, thermal stratification during the summer, the autumnal cooling cycle, and the winter thermal minimum and (3) water chemistry including the existing chemical stratification or its lack at the beginning of a seasonal period and the chemical quality of inflow.

17. KEY WORDS AND DOCUMENT ANALYSIS **PRICES SUBJECT TO CHANGE**

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Limnology* Water quality Fishes	Acid mine drainage* Fish population Tygart Lake West Virginia	08/H 08/L

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
145

22. PRICE
$6.00-2.25

EPA Form 2220-1 (9-73)

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The multi-media character of pollution resulting from the extraction, processing, conversion, and utilization of energy and mineral resources, and from industrial processsing and manufacturing, requires an approach which recognizes the complex impact of these operations on our environment.

The Industrial Environmental Research Laboratory - Cincinnati utilizes a multidisciplinary approach in the development and demonstration of technologies to effectively deal with the pollution associated with these operations. The Laboratoory assesses the environmental and socioeconomic impact of industrial and energy-related activities and identifies and evaluates control alternatives.

This report is a product of the above efforts. It describes an investigation of acid mine drainage effects on reservoir fishery populations. The Tygart River located in northern West Virginia was used as a case study. Over a two year period, this lake was surveyed. Data was collected on water quality and lake limnology. The effect of acid mine drainage on lake fish populations were documented. This report should be of interest to investigators assessing environmental damages of coal mine development and biologist concerned with the effect of acid discharges on fish population.

David G. Stephan
Director
Industrial Environmental Research Laboratory - Cincinnati

CONTENTS

Page

Introduction 1

Tygart Valley River. 4
Tygart Lake. 16

Methods 27

Results and discussion 34

Sources of acid water. 34
Water-level fluctuation and flow relationships 38
Turbidity and transparency. 45
Ice cover 50
Treatment of results for temperature and water chemistry. 50
Limnological evaluation - summer pool 102
Limnological evaluation - autumn-winter drawdown. 106
Limnological evaluation - spring pool 108
Status of fish populations 110

Literature Cited. 134

FIGURES

Page

1. Location Map. 5
2. Tygart Valley River Basin 8
3. Tygart Lake 20
4. Depth profiles of Tygart Lake at principal regulatory pool levels 21
5. Temperature and pH profiles, Lower Lake station, Cruises 1 and 2. 91
6. Temperature and pH profiles, Lower Lake station, Cruises 4 and 7. 92
7. Temperature and pH profiles, Lower Lake station, Cruises 9 and 11 93
8. Temperature and pH profiles, Lower Lake station, Cruises 13 and 16 94
9. Temperature and pH profiles, Lower Lake station, Cruises 18 and 23 95
10. Temperature and pH profiles, Lower Lake station, Cruises 24 and 27 96
11. Temperature and pH profiles, Lower Lake station, Cruises 28 and 29 97
12. Temperature and pH profiles, Lower Lake station, Cruises 30 and 31 98
13. Temperature and pH profiles, Lower Lake station, Cruise 32 99

TABLES

Page

1. Drainage area and average discharge for stations in the Tygart River Basin 6
2. Surface water quality for selected stations in the Tygart Valley River basin 10
3. Surface water quality for selected stations on the Tygart Valley River 11
4. Water quality of Grassy Run and Roaring Creek, March 1964 to 1966, Tygart Valley River basin 14
5. Morphometric data for reference elevations, Tygart Lake (English units) 23
6. Morphometric data for reference elevations, Tygart Lake (Metric units) 24
7. Survey of streams entering Tygart Lake at summer low water regulation pool level (1094 pool elevation) 36
8. Monthly ranges of regulated pool elevation and outflow, Tygart Lake, in relation to precipitation and inflow 39
9. Physical parameters for selected cruises 43
10. Surface turbidity in standard units 46
11. Secchi disk transparency in meters 48
12-1. Reference elevations (meters) for Tygart station sequence 51
12-2. Reference elevations (meters) for Sandy and Pleasant station sequences 53
12-3. Reference depths for Doe Pond station sequence 55
13-1. Reference temperatures (Celsius) for Tygart station sequence . . 56
13-2. Reference temperatures (Celsius) for Sandy and Pleasant station sequences 58
13-3. Reference temperatures (Celsius) for Doe Pond station sequence 60
14-1. Dissolved oxygen (mg/liter), values for Tygart station sequence 61
14-2. Dissolved oxygen (mg/liter), values for Sandy and Pleasant station sequences 63
14-3. Dissolved oxygen (mg/liter), values for Doe Pond station sequence 65
15-1. pH values for Tygart station sequence 66
15-2. pH values for Sandy and Pleasant station sequences. 68
15-3. pH values for Doe Pond station sequence. 70

Page

16-1. Cold Acidity (mg/liter $CaCO_3$), values for Tygart station sequence 71
16-2. Cold Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences 73
16-3. Cold Acidity (mg/liter $CaCO_3$), values for Doe Pond station sequence 75
17-1. Hot Acidity (mg/liter $CaCO_3$), values for Tygart station sequence 76
17-2. Hot Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences 78
17-3. Hot Acidity (mg/liter $CaCO_3$), values for Doe Pond station sequence 80
18-1. Total Iron (mg/liter), values for Tygart station sequence 81
18-2. Total Iron (mg/liter), values for Sandy and Pleasant station sequences 83
18-3. Total Iron (mg/liter), values for Doe Pond station sequence. . . . 85
19-1. Total Hardness (mg/liter $CaCO_3$), values for Tygart station sequence 86
19-2. Total Hardness (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences. 88
19-3. Total Hardness (mg/liter $CaCO_3$), values for Doe Pond station sequence 90
20. Tygart Lake species composition in previous years 114
21. Tygart Lake species composition expressed as numbers of fish collected in the study areas during 1966 and 1967 116
22. Distribution of fish collecting gear by areas and stations 117
23. Selectivity of collecting methods 118
24. Species catch as number /10 unit by area and gear 119
25. Species catch as grams /10 unit by area and gear 120
26. Metric size class ranges and English equivalents by species . . . 121
27. Wire hoop net catch rates by number and weight for collection areas 122
28. Gill net catch rates by number and weight for collection species. 123
29. Trammel net catch rates by number and weight for collection species. 124
30. Standing crop in metric units for species collected by rotenone census of two Tygart Lake coves, October 25, 1966 125
31. Standing crop in metric units for species collected by rotenone census of three Tygart Lake coves, August 7-9, 1967 127
32. Standing crop in metric units for managemect categories collected by rotenone census for two Tygart Lake coves, October 25, 1966. 130

Page

33. Standing crop in metric units for management categories collected by rotenone census of three Tygart Lake coves, August 7-9, 1967. 131
34. Standing crop in English units for species and management categories collected by rotenone census of two Tygart Lake coves, October 25, 1966. 132
35. Standing crop in English units for species and management categories collected by rotenone census of three Tygart Lake coves, August 7-9, 1967. 133

INTRODUCTION

In the Appalachian region south of the limits of Pleistocene glaciation, natural lakes are scarce. This deficiency is compensated by the distribution throughout the region of man-made ponds and lakes ranging in size from less than one acre to large reservoirs of more than 100,000 acres. West Virginia, in 1967, had 45 state-managed fishing impoundments with a total recreation pool area of approximately 13,400 acres (West Virginia Department of Natural Resources, 1967). Seven large reservoirs accounted for 11,900 acres or 89 per cent of this water area. Recreational use, including sport fisheries, is state-managed, although these reservoirs are not state-owned. Construction of authorized reservoirs by the Corps of Engineers will in the future increase the total impounded water managed by the state to more than 27,000 acres. The sport fishery potential of the existing acreage of flood control and hydroelectric reservoirs has been considerably diminished because of pollution from coal mine drainage. Of the 11,900 surface acres represented by large reservoirs, approximately 3500 acres (29 percent) are degraded by acid mine pollution.

The two principal reservoirs affected by acid water pollution are Lake Lynn (Cheat Lake) in Monongalia County, West Virginia, and Tygart Lake in Taylor and Barbour Counties, West Virginia. In the most recent published investigation of Lake Lynn, Menendez (1966) indicated that the pH ranged from 4.2 to 5.4 in the main lake. Rotenone sampling of a one acre area on the main lake yielded five fish. Studies conducted on Tygart Lake show a similar degradation of environmental conditions accompanied by poor fish production. Seaman and Stephens (1948) stated that the surface water at the Tygart Lake dam on several occasions showed a pH value of 5.6. They attributed the acid condition to pollution of the Tygart River by acid mine drainage. A report by the Division of Fish Management, West Virginia Conservation Commission (unpublished), gives a pH range from 4.7 to 5.4 for Tygart Reservoir water used by the city of Grafton from March 1958 to February 1959. Kinney (1962) states that as a result of acid drainage entering the Tygart River, the productivity in the main body of Tygart Reservoir is only a few ounces of fish per acre. In 1959, a one-acre rotenone sample of the Pleasant Creek Arm yielded about 1.6 ounces of fish per acre. The same year a similar rotenone census on the Doe Run Arm yielded 2 ounces of fish per acre. Fish samples in 1959 were associated with pH values ranging from 5.1 to 5.7. In 1960, the mouth of the Pleasant Creek Arm had a pH range from 5.2 to 5.9. (Division of Fish Management, unpublished). The yield of a rotenone sample at this location was approximately 40 pounds of fish per acre. Although this was a much higher standing crop than that reported for the previous year, it consisted principally of white suckers and carp. The game fish yield was less than 1 pound of largemouth bass per acre.

In 1964, Congress authorized a demonstration grant of five million dollars for reclamation and abatement of acid mine drainage in the Roaring Creek - Grassy Run Watershed near Elkins, West Virginia (Hill, 1969). This area contains a large strip mine and several smaller underground mines. It was estimated by Hill (1969) that discharge of acid from these watersheds amounted to 12.4 tons net acidity per day (hot acidity expressed $CaCO_3$). The project was initiated under the direction of the Water Supply and Pollution Control Program of the Department of Health, Education and Welfare, and was later transferred to the Federal Water Pollution Control Administration, U. S. Department of the Interior. Participating agencies included the U. S. Bureau of Mines, U. S. Geological Survey, U. S. Bureau of Sport Fisheries and Wildlife, and several West Virginia State agencies. Mine sealing and reclamation was begun in July of 1966 and terminated in September of 1967. Hill (1969) stated that following conclusion of the project work, reduction of mine drainage was evident and that continued improvement was expected. However, Hill predicted that the improvement in water quality would be a slow process. This project is of particular interest in its association with Tygart Lake, 50 stream miles below the Roaring Creek acid discharge. The FWPCA (1969a) reported 38 tons of net acidity per day at Colfax, 16 stream miles below Tygart Lake. If reclamation of the Roaring Creek - Grassy Run drainage basin was complete, the acid load received below Tygart Lake at Colfax, West Virginia, would be reduced by 32 percent. Such a reduction could result in a substantial improvement in the Tygart Lake fishery.

Review of previous work on Tygart Lake indicates that there is no existing body of data which takes into account the relationship between acid conditions and status of fish populations in the entire lake. In view of the future possibility of a substantial reduction in acid load entering the reservoir, the study was undertaken with the following objectives:

1. To make a limnological evaluation of acid conditions in Tygart Lake with emphasis on: sources of incoming acid; the development of acidity gradients from these sources; and the influence of physical factors including thermal stratification and annual drawdown.
2. To evaluate the status of Tygart Lake fish populations in relation to acid conditions.

This final report constituting the completion report for contract no. 14-16-0005-3034 incorporates information obtained under contract no. 14-16-005-2092 for an initial year of study. The investigational period covered by the report is from July 1, 1966 through December 31, 1967. Creel census proposed as a part of the second year of study was found to be impractical because of the negligible sport fishing activity on Tygart Lake.

Tygart Valley River

The Tygart Valley River has a main stream length of 132 miles from its source in northern Pocohontas County to Fairmont, West Virginia, where it joins the West Fork River to form the Monongahela River mainstem (Figure 1). It is one of the major units in the Monongahela River System. The drainage area of 1,370 square miles constitutes about one-third of the Monongahela River basin in West Virginia, and about 19 percent of the entire Monongahela River basis. The average discharge of 2,636 cubic feet per second contributes approximately 59 percent of the average Monongahela River flow at Lock 8, Point Marion, Pennsylvania. Table 1 gives

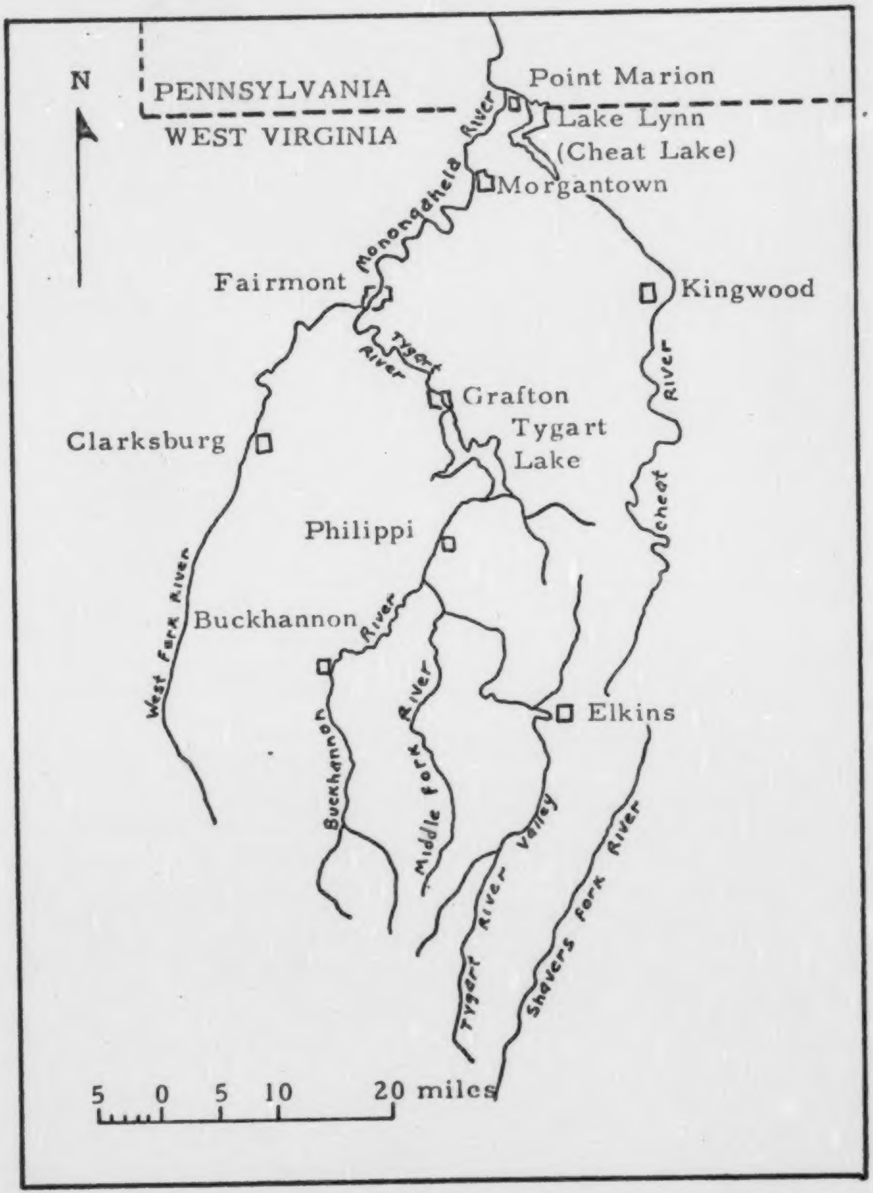

N
PENNSYLVANIA
WEST VIRGINIA
Point Marion
Lake Lynn
(Cheat Lake)
Morgantown
Monongahela River
Fairmont
Kingwood
Tygart River
Grafton
Tygart
Lake
Clarksburg
Cheat River
Philippi
Buckhannon
Buckhannon River
West Fork River
Middle Fork River
Elkins
Tygart River Valley
Shavers Fork River
5 0 5 10 20 miles

FIGURE 1. Location map, Monongahela River system in West Virginia.

TABLE 1. Drainage area and average discharge for stations in the Tygart River basin. (Friel et al, 1967).

Drainage and Station	Gaging station number	Mile point	Drainage area (square mi.)	Discharge average (CFS)
Upper basin				
Tygart Valley River				
near Dailey	500	96.2	187	345
near Elkins	505	79.5	272	496
Water Gap (Rich Mtn-Laurel Ridge)		74.7	334	
Lower basin				
Tygart Valley River at Belington	510	62.3	408	799
Middle Fork River at Audra	520	2.5	149	342
Buckhannon River at Hall	535	7.5	277	595
Tygart Valley River				
at Philippi	545	44.6	916	1842
at Grafton	560	20.6	1184	2322
at Colfax	570	6.0	1366	2636
at Fairmont		0.0	1370	
Monongahela basin				
Monongahela River at Lock 8, Point Marion, Pa.	620	90.8	2720	4484
at Pittsburgh, Pa.		0.0	7340	

additional values for drainage area and average discharge at selected stations within the basin.

The upper basin of the Tygart Valley River is a natural unit of 344 square miles entirely within the Allegheny Physiographic Province. The principal outcrop formations are sandstones of the Upper Devonian System. From the headwater in northern Pocahontas County at an elevation of approximately 4,050 feet, the main course follows the north-northeast bearing of the Deer Park Anticline for about 52 miles to Elkins in Randolph County. From Elkins, the river flows westward for five miles entering the water gap between Rich Mountain and Laurel Ridge at an elevation of approximately 1,900 feet. This point, two miles downstream from the mouth of Leading Creek, marks the terminus of the upper basin. Coal mining is undeveloped in the upper basin of the Tygart Valley River (Figure 2).

The lower basin drainage area of 1,036 square miles is within the Appalachian Plateau Physiographic Province. As the Tygart Valley River enters this province at the water gap, it passes through a series of narrow tilted outcrops of the Mississippian System. Beyond this point, the basin is characterized by geologic units of the Pennsylvanian System consisting of sandstones, shales, and extensive coal measures. The Tygart Valley River extends for approximately 75 miles through the lower basin. The river course to Fairmont is generally north-northeast, but there are several major segments alternating between northwest and northeast (Figure 2). Between Berlington and Philippi, two major tributaries, the Middle Fork River and the Buckhannon River, enter the Tygart mainstem. These two

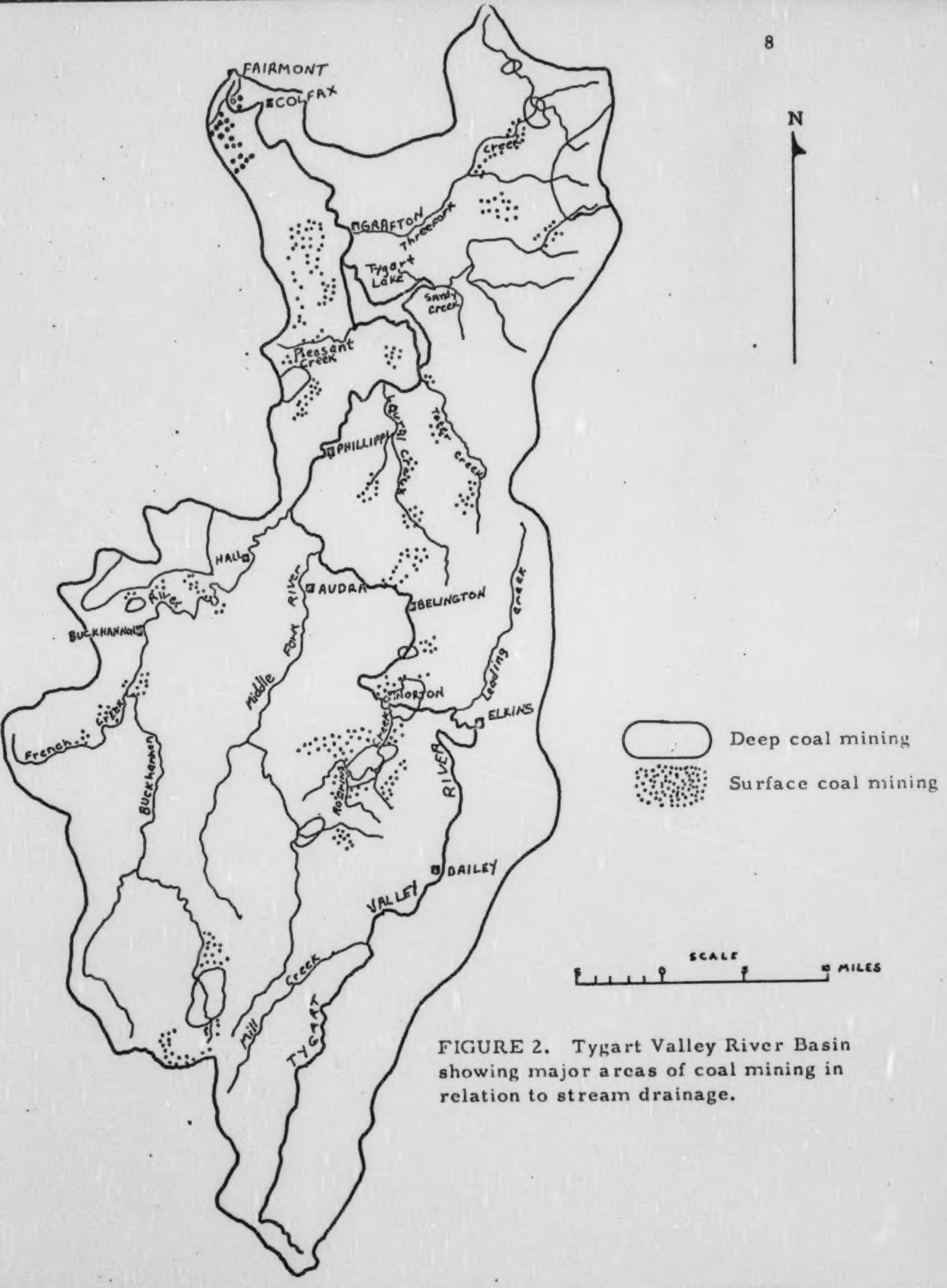

FAIRMONT
COLFAX
Creek
GRAFTON
Threefork
Tygart Lake
Sandy Creek
Pleasant Creek
Laurel Creek
Teter Creek
PHILLIPPI
HALL
River
AUDRA
BELINGTON
BUCKHANNON
Middle Fork River
Leading Creek
NORTON
ELKINS
French Creek
Buckhannon
Roaring Creek
RIVER
DAILEY
VALLEY
Mill Creek
TYGART
N
Deep coal mining
Surface coal mining
SCALE
5
0
5
10 MILES

FIGURE 2. Tygart Valley River Basin showing major areas of coal mining in relation to stream drainage.

drainages comprise 41 percent of the lower basin area and constitute 31 percent of the entire basin (Table 1). The mainstem lower basin, occupying 44 percent of the entire basin, is the largest unit within the Tygart drainage system.

Selected water quality parameters of acid mine drainage are presented in Tables 2 and 3. Data in these tables were compiled from sources which appeared to have an adequate sampling base within comparable time spans. In Table 2, the data for the upper basin stations (Friel _et al_, 1967) are representative of base flow samples for 1960, 1961, 1963, and 1964. Lower basin station data represent sampling at all seasons for the year 1960 through 1963. In Table 3, data for the upper basin station near Dailey and the Grafton station below Tygart Lake (Henry, 1967) are representative of a three year span from 1964 through 1966 in which samples were collected throughout the year, whereas the Philippi and Colfax data (FWPCA, 1969) are believed to represent 1966 summer samples. Because of these discrepancies in sampling periods, there are minor inconsistencies between stations (_ie_ in Table 3 the Grafton data are inconsistent with the Philippi and Colfax data).

Results for analyses presented by Friel _et al_ (1967) for the Dailey and Elkins stations show carbonate hardness to be 75 to 96 percent of the total hardness. This is supported by the proportionately high alkalinity and low sulfate values for these stations in Tables 2 and 3. Analyses of total dissolved solids (Friel _et al_, 1967) for Dailey ranged from 40 to 54 mg/liter. Total hardness is below the upper limit of 60 mg/liter for a soft water. Characteristics of minimum pH greater than 6.0, low sulfate and relatively high alkalinity are indicative of the fact that surface and

TABLE 2. Surface water quality for selected stations in the Tygart Valley River basin. Adapted from Friel et al 1967. HCO_3 and SO_4 as mg/liter; hardness as mg/liter $CaCO_3$. Mile point refers to distance in stream miles from the mouth. Chemical data for each station based on 3 to 7 samples from the years 1960 to 1964.

Drainage and Station	Sta. NO.	Mile point	pH		HCO_3		SO_4		Hardness			
									Total		non-CO_3	
			min	max	min	max	min	max	min	max	min	max
Upper basin												
Tygart Valley River near Dailey	500	96.2	6.9	8.2	26	44	4	7	26	37	1	5
near Elkins	505	79.5	6.2	6.9	14	38	7	9	18	36	2	7
Lower basin												
Tygart Valley River at Belington	510	62.3	4.8	6.1	1	7	34	62	32	65	31	58
Middle Fork River at Audra	520	2.5	5.8	6.2	2	5	8	9	7	9	3	8
Buckhannon River at Hall	335	7.5	5.3	6.6	2	7	15	25	16	25	10	22
Tygart Valley River at Phillipi	545	44.6	5.8	6.4	1	6	22	38	26	40	20	39
at Colfax	570	6.0	4.4	6.6	0	5	22	49	22	44	21	44

TABLE 3. Surface water quality for selected stations on the Tygart Valley River. Data sources as indicated in the footnotes. Acid load as net tons H_2SO_4/day. Acidity, alkalinity and hardness as average mg/liter $CaCO_3$; sulfate and iron as average mg/liter.

Station	Station number	Mile point	Acid load	pH min	pH max	Acidity	Alkalinity	Hardness	Sulfate	Iron
Upper basin										
near Dailey	MT-54[a]	96.2		6.3	7.3	7	29	34	0	0.2
Lower basin										
at Philippi	108[b]	44.6		4.8	7.4	23	7	76	57	0.4
at Grafton	MT-11[a]	20.6	14[b]	4.2	6.4	11	7	44	56	0.6
at Colfax	104[b]	6.0	38[b]	4.7	7.5	28	2	55	33	0.3

Data Source

[a] Henry 1967: chemical data for 1964-1966

[b] FWPCA 1969: chemical data for 1966

ground water drainage from the Devonian strata of the upper basin is not associated with coal mine drainage. The Tygart Valley River in the upper basis is a calcium bicarbonate type, soft and with low buffering capacity.

Examples of comparable surface water series free of mine pollution are difficult to find among published results for analyses in the lower basin. Single sample analyses for apparently unpolluted tributaries of the Middle Fork River (Right Fork and Laurel Creek) are given by Friel et al (1967). These samples, collected in September 1963 during a base flow period, show hardness and alkalinity values less than 10 mg/liter as $CaCO_3$. The pH was slightly acidic (pH 6.2 to 6.4). Sulfate values were 4 and 7 mg/liter. Assuming that these samples were representative, it appears that lower basin surface waters free of mine drainage are of a marginal calcium sulfate type, very soft, and poorly buffered.

Coal mining areas are widely distributed through the lower basin of the Tygart Valley River (Figure 2). As a result of mine drainage from these areas, the Tygart Valley River is continuously polluted from the confluence of Roaring Creek (Figure 2) to the head of the Monongahela River at Fairmont (FWPCA, 1969a). This 72-mile reach includes 97 percent of the Tygart mainstem in the lower basin and 55 percent of the river from its source. Roaring Creek and Grassy Run join the Tygart Valley River near Norton, about two miles below the water gap. The combined basin of these two tributary streams occupies an extensively mined area of 32 square miles in which the normal separation between watersheds was eliminated by diversion through a large underground mine (Hill, 1969). Some features of the water chemistry as reported by Hill (1969) are presented in Table 4. Values for pH, acidity, and sulfate demonstrate the deterioration of water quality that has taken place in this small basin. Although the flow entering the Tygart Valley River is small, 46 CFS, the 1964 to 1966 average daily discharge of 13.2 tons of sulfuric acid may represent the maximum acid load from any single source above Tygart Lake.

Figure 2 shows areas of surface and deep mining which are potential sources of mine drainage downstream from the Roaring Creek confluence. Major mining locations are distributed from Norton to and below Berlington and in the vicinity of Philippi. Above Tygart Lake surface mining is extensively distributed in the Laurel Creek and Teter Creek basins. Sandy Creek and Pleasant Creek which are tributary to Tygart Lake; Three-fork Creek and the Tygart River mainstem below Colfax; and major tributaries of the Tygart River, the Middle Fork River and Buckhannon River, all have major areas of mining and further demonstrate the extent of potential mine pollution in the lower basin.

The realization of this potential is demonstrated in Tables 2 and 3. Lower basin stations on the mainstem of the Tygart Valley River (Berlington, Philippi, Grafton, and Colfax) have minimum values of less than pH 5.0 in comparison with the minimum pH values of 6.2 and 6.3 at Elkins and Dailey in the upper basin. Low alkalinity corresponds with comparatively high acidity values. The maximum values for hardness, sulfate, and iron show substantial increases over values at Elkins and Dailey. The 72-mile reach of the Tygart Valley River below Roaring

TABLE 4. Water quality of Grassy Run and Roaring Creek, March 1964 to June 1966, Tygart Valley River basin. Adapted from Hill, 1969. Acid load as average tons H_2SO_4/day. Acidity and hardness as average mg/liter $CaCO_3$; sulfate and iron as average mg/liter.

Stream	Acid load	pH median	Acidity	Hardness	Sulfate	Iron total	Discharge CFS
Grassy Run	11.4	2.6	660	450	990	110	6
Roaring Creek	1.9	3.3	110	100	170	5	40

Creek has been designated by the FWPCA (1969a) as continuously affected by mine drainage. The term "continuously affected" is applied to streams which are "significantly degraded" all or nearly all of the time.

The FWPCA (1969b) provides information on potential acid loading from mine drainage sources. On the basis of reported field inventories the acid load for the coal-mine sources in the entire Tygart Valley Basin was 48.0 tons of net acidity per day. Sources above Berlington average 12.8 tons of net acidity per day — nearly all from Roaring Creek and Grassy Fork. Below Berlington the mine-drainage source load is relatively moderate in relation to the large drainage area. The total, including the Middle Fork and Buckhannon basins, is 7.0 tons of net acidity per day. The maximum load reported is 28.2 tons of net acidity per day produced by mine-drainage sources in the basin below Tygart Lake. The drainage area above Tygart Lake is 86 percent of the entire basin; however, it includes less than one-half of the inventoried acid load from coal-mine sources.

Potential sources of acid mine drainage in the Middle Fork and Buckhannon River basins are shown in Figure 2. Inventoried acid loadings of 0.5 and 1.5 tons of net acidity per day were reported respectively for the Middle Fork and Buckhannon Basins by the FWPCA (1969b). One-third of the average discharge for the entire Tygart Basin is contributed by these tributary rivers, but the combined basins contribute only 4 percent of the 48 tons of net acidity per day. This relatively moderate acid loading has deleterious effects. The FWPCA (1969b) stated that

"Water quality of the Buckhannon River is degraded over nearly its entire length as a result of coal mine drainage." Table 2 shows the Buckhannon River to be significantly affected at Hall. Conditions in the Middle Fork River do not appear to be as severe. According to the FWPCA (1969b) water quality of the Middle Fork River is degraded by acid drainage received in the basin tributaries below Cassity.

Acid mine pollution in the lower basin of the Tygart Valley River appears to be pervasive and substantial. Surface waters of the principal streams can be classified as predominantly within the range of moderate hardness (61 to 120 mg/liter as $CaCo_3$) and of a calcium sulfate type. Reduced alkalinity, moderately high acidity and pH values below pH 5.0 are generally characteristic of the Tygart River in the lower basin. Although acid loading by coal mine drainage sources is greatest below Tygart Lake, it is to be expected that the lake will be subject to significant acid loading from the Tygart Valley River during a large part of the year.

Tygart Lake

Tygart Lake is a multiple-use reservoir located approximately 22.7 river miles above the mouth of the Tygart Valley River. The reservoir is maintained by the Army Corps of Engineers as part of the Upper Ohio River Basin flood-control system. Relevant basin relationships of the reservoir are shown on the location map (Figure 1). Operation by the Army Corps of Engineers, Pittsburgh District, is primarily for flood control and navigation augmentation of flow in the upper Monongahela River (Corps of Engineers, 1969). Some of the more important secondary uses are: provision of a domestic water supply for the city of Grafton, reduction in the intensity of pollution resulting from acid mine drainage, and recreation including park visitation, boating, swimming, and fishing. The administration of Tygart Lake State Park and management of recreation and fish and game are carried out by the West Virginia Department of Natural Resources under provisions of a long-term license granted by the Department of the Army (Corps of Engineers, 1969).

The Tygart Lake Dam is located 2.25 miles south of Grafton in Taylor County, West Virginia. It is 151.4 miles upstream from the point of origin of the Ohio River (confluence of the Monongahela and Allegheny Rivers) at Pittsburgh, Pennsylvania. Construction of the dam was completed in February, 1938, and the reservoir has been continuously in operation since that time. Specifications given in the following description are those given in general public information maps and leaflets of the U. S. Corps of Engineers. Reference has also been made to the Sedimentation Survey (Corps of Engineers, 1961).

Dam

The dam construction is a concrete gravity type with a top length of 1,921 feet (585.9 meters) and base width of 207 feet (63.1 meters).

Spillway

The spillway occupies a 489-foot (149.0 meters) section along the top center of the dam. It is an uncontrolled concrete gravity type, ogee-shaped. The crest elevation is 1,167 feet (355.7 meters). Height above the original river bed is 207 feet (63.1 meters).

Outlet Works

The main outlets include 8 conduits, each of which is controlled by a hydraulically operated slide gate, 5.67 x 10.0 feet (1.7 x 3.0 meters). In addition to the service gate each outlet has an emergency gate. The inlet (lake side of the dam) invert elevation of the main outlets is 995 feet (303.5 meters). The inlet center elevation is 1,000 feet (304.8 meters).

Low discharge outlets include 2 conduits, each of which is regulated by a 4 foot (1.2 meters) needle valve and controlled by a hydraulically operated slide gate, 5.67 x 6 feet (1.7 x 1.8 meters). The inlet (lake side of the dam) invert elevation of the low discharge outlets is 990.67 feet (302.2 meters). The inlet center elevation is 993.67 feet (303.1 meters).

The main outlets are on line, at the same elevation in the central section of the dam below the spillway. One low discharge outlet is located at each end of the series of 8 main outlets. Outlet works are protected by trash racks.

Stilling Basin

The stilling basin is formed by a concrete dam, 33 feet (10.1 meters), located 223 feet (68.0 meters) downstream from the spillway base.

City of Grafton Water Supply Intakes

The water supply conduit consists of one 24-inch (0.61 meters) pipe. Intakes are located at elevations of 1076.5 feet (328.1 meters), 1044.75 feet (302.5 meters). Location of intakes is on the east side of the dam.

Tygart Lake storage is regulated in relation to pool stages at hydrographic reference elevations of 1,010 feet (307.8 meters) and 1,094 (333.4 meters). The following outline of storage regulations is based on the Corps of Engineers (1961) description of the operational plan.

Elevation of 1,010 feet is the minimum pool elevation. All of the useable reservoir storage capacity lies above this elevation. Except for temporary flood impoundments, the pool level is maintained near this elevation for the period from December 16 to the end of March.

From about April 1 -June 15, the excess inflow is impounded to establish the maximum summer low-water regulation pool of 1,094 feet. Storage at this elevation establishes the initial summer recreation pool level, although the principle function is provision for later navigation augmentation release. The reservoir is not maintained above elevation 1,094 feet. All storage above this level represents temporary flood-water impoundment, and in the summer, the flood control capacity lies entirely above this elevation.

The drawdown period begins about July 1 and extends to December 15. The release is gradual and initially it is primarily related to augmentation of flow in the Monongahela River. The release over this period established the minimum winter pool for flood-control capacity above elevation 1,010 feet. The maximum capacity of the reservoir is at spillway level, elevation 1,167 feet (355.7 meters); however, this is not an operational level.

At the summer-pool elevation of 1,094 feet, the Tygart Lake basin is about 10 miles (16 kilometers) long (Figure 3). In its narrow winding course, the main lake channel trends generally northwest. From the Tygart Valley River inlet to the 5-mile point, the breadth increases gradually from 230 feet (70 meters) to about 1,240 feet (380 meters). The 5-mile sector marks a transitional broadening from river-like to more lake-like widths. Just above the Pleasant Creek Arm the breadth is about 1,800 feet (550 meters). The maximum breadth, 2,380 feet (725 meters) is at the 1-mile point. Below this the lake narrows to about 1,500 feet (450 meters) at the dam.

The sequential changes in depth are shown in Figure 4. Abruptly increasing depth is characteristic of the narrow sector from the inlet to the Sandy Creek.

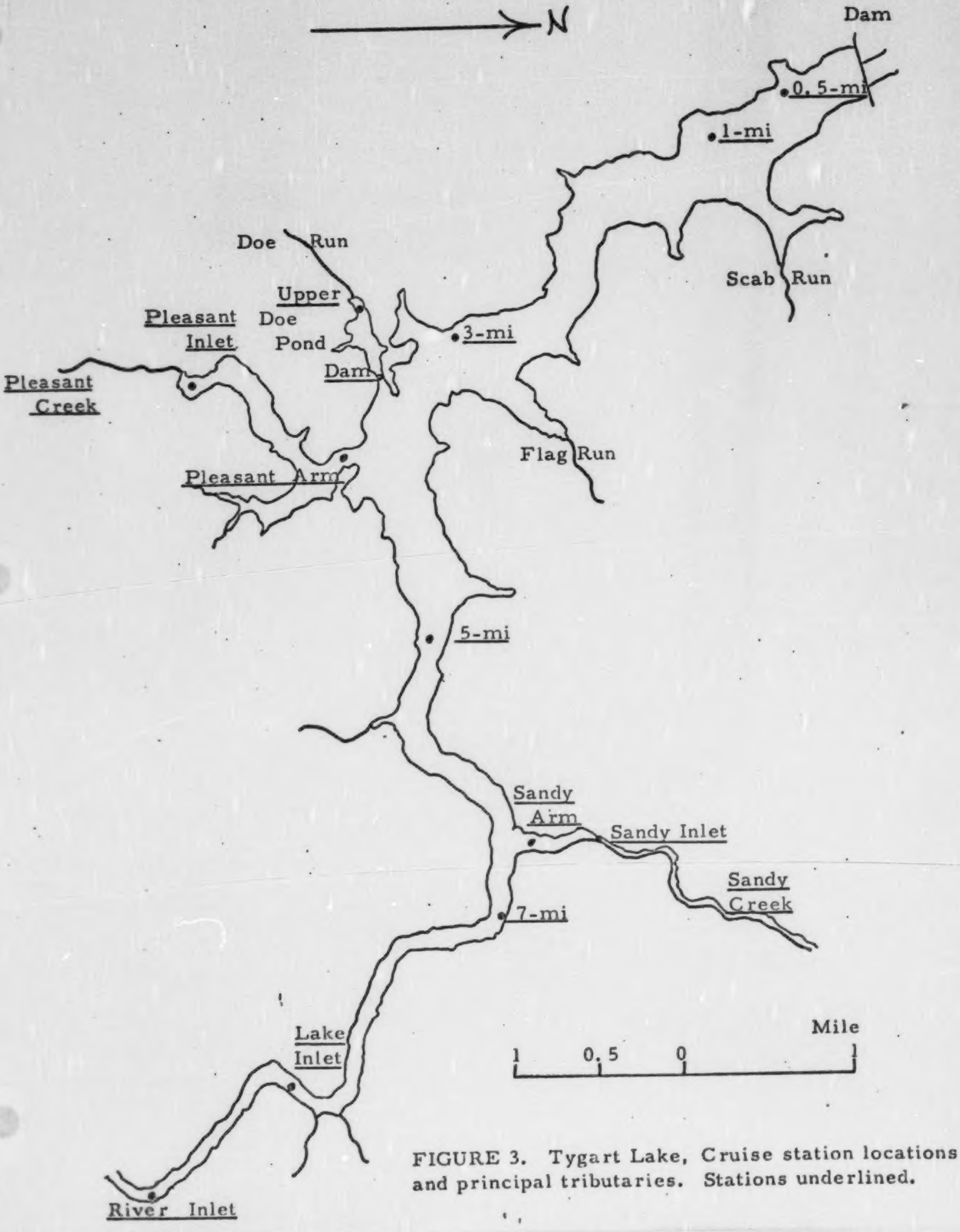

N
Dam
0.5-mi
1-mi
Scab Run
Doe Run
Upper Doe Pond
Pleasant Inlet
Pleasant Creek
Dam
3-mi
Flag Run
Pleasant Arm
5-mi
Sandy Arm
Sandy Inlet
Sandy Creek
7-mi
Lake Inlet
River Inlet
Mile
1
0.5
0
1

FIGURE 3. Tygart Lake, Cruise station locations and principal tributaries. Stations underlined.

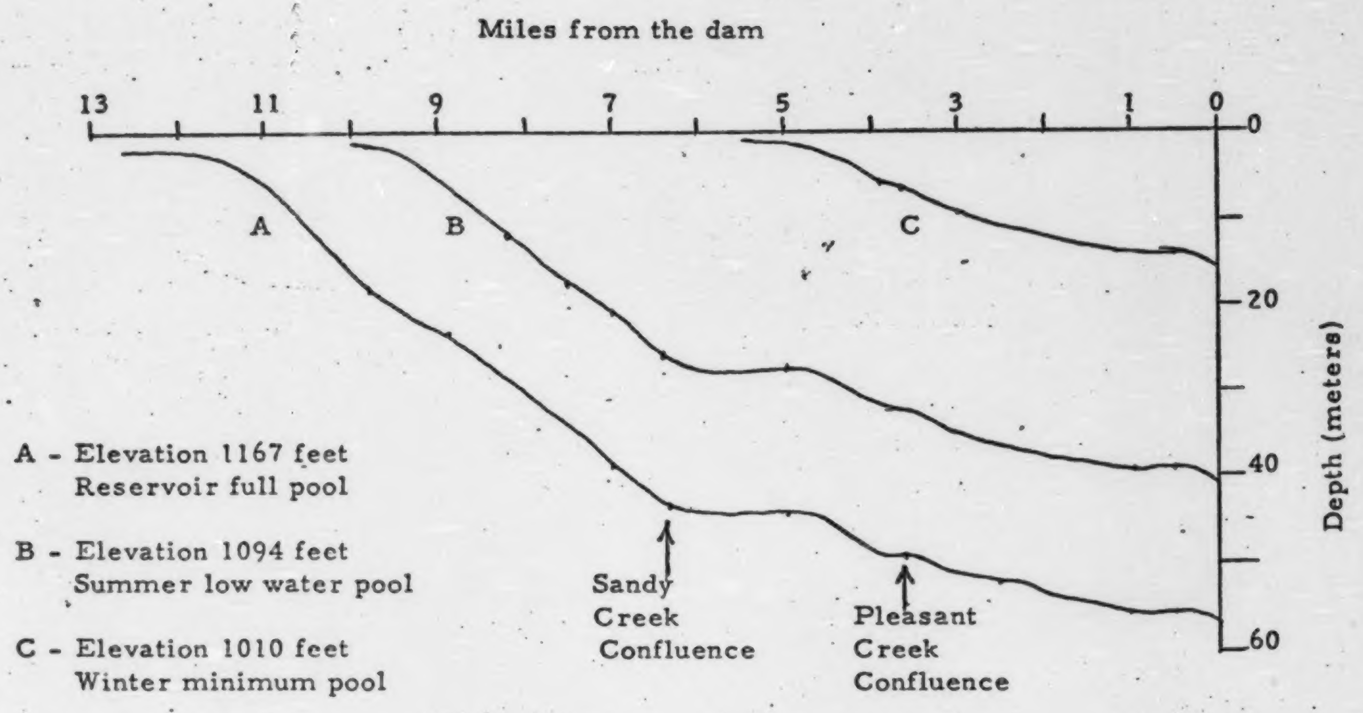


FIGURE 4. Depth profiles of Tygart Lake at principal regulatory pool levels. Based on U.S. Army Corps of Engineers Sedimentation Survey of 1959 (1961).

confluence at 6.4 miles. Although the lake breadth remains narrow there is very little change in depth from the Sandy Creek confluence to the 5-mile point. The leveling off is related to the conformation of the original valley drainage. The sedimentation survey of 1959 (Corps of Engineers, 1961) does not show any marked accumulation of sediments in these areas. A stated conclusion of the survey was that there were no delta areas. From the 5-mile point, the main lake channel slopes gradually to the dam with a net increase in depth of 13 meters (43 feet).

Even though it is winding, the basin at summer pool level is relatively simple in form (Figure 3). The only major arm at this level is the 1.4 mile (2.2 kilometers) tributary channel of Pleasant Creek. The arm of Sandy Creek is about 0.4 of a mile (0.6 kilometers) long.

The Doe Pond subimpoundment is formed by a low dam across the Doe Run tributary valley. Doe Pond with a surface area of about 13.8 acres (5.6 hectares) is isolated from the parent reservoir at pool levels below the 1,094 foot elevation. Communication between the two bodies of water is established during periods of flood storage above the summer pool level.

Morphometric parameters are given in Table 5 (English units) and Table 6 (metric units). Tygart Lake with an area of 1,740 acres at low-water regulation (summer) pool is a relatively small reservoir compared with the average of 8,400 acres for the 1,065 United States reservoirs on which information has been compiled by the reservoir-research program of the Bureau of Sports Fisheries and Wildlife

TABLE 5. Morphometric data for reference elevations, Tygart Lake[a] (English units).

	Units	Minimum (conservation) pool	Low water (regulation) pool	Maximum (reservoir full) pool
Elevation	ft	1010	1094	1167
Maximum depth	ft	48	132	205
Outlet depth[b]				
main	ft	15	99	172
low discharge	ft	19	103	176
Mean lake depth	ft	16	63	84
Mean depth/max depth		0.32	0.48	0.41
Maximum length	mi	6.4	10.1	13.1
Mean breadth	ft	800	1420	2160
Shoreline length	mi	17	27	62
Shoreline development		4.9	4.6	7,6
Area	acres	620	1740	3430
Total volume	acre-ft	9690	109,600	287,700

[a] Based on data provided by the U.S. Army Corps of Engineers.

[b] Depth of outlets based on intake invert elevations.

TABLE 6. Morphometric data for reference elevations, Tygart Lake[a] (metric units)

	Units	Minimum (conservation) pool	Low water (regulation) pool	Maximum (reservoir full) pool
Elevation (mean sea level)	m	308	333	356
Maximum depth	m	15	40	62
Outlet depth[b]				
main	m	5	30	54
low discharge	m	6	29	55
Mean lake depth	m	5	19	26
Mean depth/max depth		0.32	0.48	0.41
Maximum length	km	10.3	16.2	21.1
Mean breadth	km	0.24	0.43	0.66
Shoreline length	km	27	43	100
Shoreline development		4.9	4.6	7.6
Area	ha	251	704	1388
Total volume	$m^3 x 10^6$	12	135	355

[a] Based on data provided by the U.S. Army Corps of Engineers.

[b] Depth of outlets based on intake invert elevations.

(Jenkins, 1968). In West Virginia, there are currently (1970) five Corps of Engineers reservoirs with summer pools greater than 1,000 acres. Also falling within the size classification are two authorized Corps of Engineers reservoirs and Lake Lynn (Cheat Lake), a hydroelectric power reservoir. Among these eight impoundments with summer pool areas ranging from 1,050 acres to 7,175 acres, Tygart Lake ranks fifth. In relation to volume, Tygart Lake ranks third among the seven largest reservoirs ranging in volume from 46,500 acre-feet to 580,900 acre-feet. Maximum depths were not available for group comparison, but the change in rank suggests that Tygart Lake is relatively deep in relation to its surface area. This is supported out by comparison of mean depths for the seven largest reservoirs. Tygart Lake ranked second within a mean depth range from 81 to 19 feet for the group. In a natural lake the ratio of mean depth to maximum depth serves as indication of basin departure from a conical form. In an impoundment where the maximum depth is at the outlet end of the lake, this ratio is not so clearly a useful parameter. The relatively high value of 0.48 (Table 4) however supports the idea that Tygart Lake had a deep basin in relation to its surface area. The transverse range profiles of the Corps of Engineers (1961) indicate steep valley slopes extending well below the summer pool 1,094 foot elevation. At minimum pool elevation 1,010, the mean depth to maximum depth ratio becomes 0.32 which is approximately that of a cone. This reduction in the ratio would occur in a basin with a U-shaped transverse profile.

Shoreline development values of reservoirs are commonly much greater than those of natural lakes because tributary valleys flooded by impounded water enormously increase the extent of shoreline. The shoreline development of 4.6 for Tygart Lake (Table 5) at low-water pool elevation 1,094 is not particularly high for a reservoir. In comparison, Sutton Lake in West Virginia has a value of 7.3 and Deep Creek Lake (Maryland), a reservoir in the Monongahela Basin, has a value of 7.1 (Jenkins, 1968). Of the 210 reservoirs listed by Jenkins (1968) at least one-half show substantially higher shoreline development values than Tygart Lake. With storage of flood water, shoreline development may be expected to increase as the basin outline becomes more dendritic in form. At the full-pool elevation 1,167 feet, the shoreline development of 7.6 for Tygart Lake (Table 5) is comparable to the values for Sutton and Deep Creek reservoirs which have somewhat dendritic basin outlines.

METHODS

The project work commenced with a survey of streams tributary to Tygart Lake with the principal objective of locating major sources of acid water. Elements of the survey included preliminary location of streams with the aid of topographic maps, observation of physical characteristics, and collection of water samples for chemical analyses. Water chemistry parameters included pH, total hot and total cold acidity, total alkalinity, and total hardness. Sample collection following preliminary exploration was conducted over a three-day period from July 11 to July 14, 1966.

Field work for the limnological survey began on July 18, 1966, and continued to December 1967. Organization of the field program was based on a series of station survey units. Each unit, constituting a limnological cruise, consisted of physical-data collection and water-sample collection for a given sequence of main lake and tributary-arm stations. Altogether in the 18 months of field work thirty-two such limnological cruises were made. Owing to a number of circumstances, the make-up of station sequences varied considerably over the study period. Despite this variation, the coverage of field locations was substantial and more than adequate for meeting the investigational objectives. Consideration is given to this point in the description of stations which follow.

The main lake sequence was initially made up of two river inlet stations

(Figure 3) at 12-mile and 9-mile locations; a lake inlet station just below the second river station at the 9-mile point; and stations at maximum depth for 7, 5, 3, 1, and 0.5-mile points along the main lake channel. Maximum depth in each station area was located by trial soundings for the first cruises, and the stations were located on subsequent cruises by alignment of the boat with landmarks. This procedure was not entirely satisfactory; later for comparison with bottom elevations given in the Corps of Engineers sedimentation survey (Corps of Engineers, 1961) indicates that the main lake deep channel was often missed; especially at the 1-mile station where the channel is relatively narrow. It was considered to be impracticable to use buoys to mark the stations because of fluctuating water levels and potential interference by public boaters. After two cruises, it became evident that there were too many stations and the main lake series was reduced to a single river station (usually the lower one) with stations at the lake inlet, 5-mile and 1-mile points. In May, 1967, substitution of the 0.5-mile for the 1-mile station was made because of the better recovery of known maximum depth values. As the pool levels changed with drawdown and flood storage, the paired river inlet and lake inlet locations were shifted. The actual sites ranged from about 6.5 miles during winter minimum-pool stages to more than 10 miles from the dam during flood stages. An effort was made to obtain a consistant relationship between the inlet locations based on a criterion of appreciable current at the river inlet and no or only slight current at the lake inlet. During flood stages, it was not possible to use this as a consistent basis of judgement.

On the basis of the preliminary survey work, two tributary arm sequences and a subimpoundment sequence were organized as part of the limnological cruise unit. As reported here, each arm sequence consisted of stations on the tributary stream above the inlet, and arm-inlet stations below the point of stream inflow and an arm station at the mouth of the arm where it entered the lake. Intermediate areas were also initially sampled in the two arms but these stations were later omitted because of the work load. The arm sequences selected were Sandy Creek because it proved to be an important acid source, and Pleasant Creek because of the importance assigned to it in previous fishery investigations.

The Doe Pond subimpoundment sequence consisted of a station just above the dam at the deepest point and a station in the upper shallow water section of the pond. Doe Run was sampled only a few occasions during the entire course of the study, because the swampy character of the lower stream reach made it difficult to gain access for sampling.

Physical data collection included Secchi disk transparency determinations where depth was sufficient. An all-white 20 centimeter Secchi disk was used. Values were reported to the nearest 0.1 meter. A U. S. Geological Survey turbidity tape graduated to a lower limit of 7 units was used to make field observations of surface turbidity. White both instruments are useful for general survey, they are lacking in precision under the usual field conditions. The values given in this report should be considered as approximations and are best compared in terms of marked differences. In 1967, water sample collections included vertical series for turbidity determination.

Vertical temperature series have been used in this study as a basis for thermal classification of strata. Temperature measurements were made customarily at the surface, at 0.5 meters depth, and at 1 meter intervals from the surface to the bottom. In some cases (Cruises 1 and 3) intervals were greater than 1 meter. Readings were made to the nearest 0.2°C with a YSI Thermister Thermometer. A standard YSI general purpose probe with a 200 foot lead was used in conjunction with the meter. In use the thermister lead was attached to a sounding line and depth intervals were read from the sounding line markings. The instrument was standarized with a precision mercury thermometer before each day of work in the field. Reading precision is considered to be with ±0.2°C and accuracy is considered to be within ±0.5°C.

Water samples were obtained with a 3.1 liter brass Foerst Kemmerer Sampler. The number of samples that could be taken at any given station was restricted by the time required for completion of analyses in the laboratory. Rotation of personnel made it possible to increase the analytical output beginning in May of 1967. With the increased capacity for chemical analysis, water samples at the deep water stations were generally collected at 5-meter intervals from the surface to the bottom. In 1966 and early 1967, sample depth intervals were set up in the field on the basis of discontinuities which appeared in the temperature series. As a consequence, the sampling intervals for this period were irregular.

Standard 300 ml BOD bottles were used to transport water samples from the field to the laboratory. Transfer from the Kemmerer sampler was made by connecting the sampling port to a linked train of 4 to 5 sample bottles. The first bottle in the train was reserved for oyygen analysis because it represented an exchange of 3 to 4 times the bottle volume. Analyses were generally carried out within 24 hours of the sample collection time. Occasionally it was necessary to hold samples for longer periods. When storage was necessary, samples were refrigerated.

The analytical parameters included in this report are pH, total cold and total hot acidities, total hardness, total iron, and dissolved oxygen. In addition, data were obtained from a limited series of total alkalinity determinations.

Determinations of pH were made with a Beckman Expandomatic pH meter. Total cold acidity was determined by titration of a 100 ml sample with 0.02 N sodium hydroxide to an endpoint pH of 8.3 using the pH meter. The procedure for determination of total hot acidity involved boiling a 100 ml sample for 2 minutes followed by titration with 0.02 N sodium hydroxide to an endpoint of pH 8.3 using phenolphthalein as the endpoint indicator. When pH values were greater than pH 4.5 priority was given to the analyses for cold total acidity; consequently, the hot acidity results are lacking or deficient in some cruise units. Results for total cold and hot acidities are reported as milligrams per liter calcium carbonate.

Total hardness was determined by the EDTA titrametric method. The procedure followed was essentially that given in the 12th edition of Standard Methods (APHA et al, 1965). The sample size used varied from 25 ml to 50 ml. In view of these small sample sizes, precision for the determinations is probably not better than ±5 mg per liter. Results for total hardness are reported as milligrams per liter calcium carbonate. Total iron was determined by the phenathroline method as given in the 12th edition of Standard Methods (APHA et al, 1965). Photometric measurements were initially made with a Klett-Summerson Colorimeter. Later in the study, sample readings were obtained with a B&L Spectronic 20 Colorimeter. Results are reported as miligrams per liter of total iron. Precision was estimated to be within ±0.05 milligrams per liter. Dissolved oxygen determinations were made by the azide modification of the standard Winkler method (APHA et al, 1965). Titration of a 100 ml or 200 ml sample was made with 0.25 N sodium thiosulfate. Results are reported as milligrams of oxygen per liter. Precision and accuracy should be well within one milligram per liter. Alkalinity determinations were made by titration of 100 mililiter samples with 0.02 N sulfuric acid. An equivalence pH of 5.1 determined with a pH meter was used because of the low range of alkalinity (APHA, 1965).

Fish survey for population status evaluation was conducted over a period of one year from August 1966 to August 1967. The fishing gear used included hardware cloth hoop nets, standard hoop nets, experimental gill nets and a trammel net.

The hardware cloth hoop nets (wire hoop nets) consisted of 3 spaced hoops covered by ½ inch mesh hardware cloth - supported by 1 inch thick slats. These wire hoop nets had a single throat with a 3 to 5 inch opening. The standard hoop nets of 1 and 2 inch mesh failed to take fish in the initial sets and their use was then discontinued.

The experimental gill nets were of multifilament nylon construction with successive 25 by 6 foot panels of 3/4 inch, 1 inch, 1¼ inch, 1½ inch, and 1 3/4 inch mesh (square measure). This proved to be the best gear for collecting a variety of species. A single 75 foot trammel net of 2 inch mesh proved useful for collecting larger fish.

Stations fished with combinations of gear included the lake inlet (9-mile), upper lake (5-mile), lower lake (3-mile, 1-mile, and 0.5-mile), Sandy Arm (inlet and arm sites) and the Pleasant Creek Arm (inlet and arm sites). In 1966 one or two periods of fishing were conducted at each station beginning on August 16 and terminating on November 20. The sequence was repeated with one to three fishing periods at each station beginning March 15 and terminating June 29, 1967

Rotenone census of selected cove areas was conducted with application of 1.5 ppm of Dry Nox fish (Penick). This is equivalent to a concentration of 0.075 ppm pure rotenone which is 3 times the standard dose. Previous experience had indicated that heavy applications are required in acid water. Application was made by pumping pre-mixed slurry at successive depth levels. A blocking net was used at the open end of the cove site. Fish pick-up was conducted for 2 days following application. In 1966 a one acre (0.4 hectares) site at the Pleasant Creek inlet and a 1.5 acre (0.6 nectares) main lake cove, Ford Island, were censused on October 25, 1966. Sites censused from August 7 to 9, 1967 included inlet locations of 1.05 acres (0.42 hectares) in the Sandy Creek Arm, 1.20 acres (0.48 hectares) in the Pleasant Creek Arm and 1.70 acres (0.69 hectares) at the mouth of the Lick Run Arm.

RESULTS AND DISCUSSION

Sources of Acid Water

Preliminary to limnological study a survey was made in July, 1966, of streams entering Tygart Lake at summer low water regulation pool level (1,094 pool elevation). Reconnaissance was made by boat and by onshore exploration. The survey objectives included collection of water samples for analyses; measurement of channel widths between high water marks; a search for evidence of coal-mining activity in the vicinity of the lake; and ferric hydroxide (yellow boy) staining as an indication of mine drainage. U. S. Geological Survey 7.5-minute quadrangles show that in addition to the Tygart River, 17 named and unnamed streams enter Tygart Lake within the survey area. At the time of the survey, July 11-14, 1966, only four of these streams had sufficient flow to permit collection of water samples. Samples were collected subsequently from three additional streams at later periods during the study. A group of eleven streams were never sampled: Scab Run, Flag Run, Frog Run, Cove Run, Big Cove Run, and six unnamed tributaries. Streams in this last group were either intermittent or small 1st and 2nd order drainages. They were surveyed and no evidence of ferric hydroxide (yellow boy) deposits or mining activity was found. The drainage basins of these streams are not within the areas of coal mining shown in Figure 2. It was assumed that streams in this group were not sources of acid water.

The results of chemical analyses are given in Table 7 for streams sampled during the survey period and at subsequent periods. The small first and second order drainages are all characterized by relatively high pH, low acidity, and low hardness. Predominantly non-carbonate hardness (presumably sulfate) is characteristic of the Doe Pond outflow, Doe Run, and Shaw Run. Predominantly carbonate hardness is indicated for the unnamed Doe Pond outflow and Stoney Run. Since alkalinity was not determined for Lick Run the hardness cannot be classified. The field survey showed no evidence of mine drainage entering these small streams. The drainage of principal interest in this group is Doe Pond which served in this study as the principal unit for comparison with Tygart Lake.

Pleasant Creek, a third order stream, is of major interest in its relationship to the Pleasant Creek Arm. This arm of the lake was considered by Robinson and Preston (1961) to be the least polluted section of the reservoir and to provide most of the limited fishing in Tygart Lake. This appears to have been a generally held opinion among fishermen and biologists on the basis of informal contacts made during the course of the study. Characteristics of relatively high pH and low acidity in Table 7 tend to support this idea. The hardness value of 257 mg/liter would be of major interest if it represented carbonate hardness because this would indicate a potentially significant source for neutralization of acid water in the upper section of the Pleasant Creek Arm. The low alkalinity for Pleasant Creek indicates that the hardness is substantially non-carbonate. In fact, it probably represents calcium and magnesium sulfate. Figure 2 indicates the presence of surface coal mining in association with Pleasant Creek and the U. S. Geological

Table 7 . Survey of streams entering Tygart Lake at summer low water regulation pool level (1094 pool elevation). Mile points and elevations represent subsurface lake channel confluence points. Stream order refers to the Horton classification. Acidity, alkalinity and hardness stated as mg/liter of $CaCO_3$.

	Location					Water analyses				
							T. acidity			
Stream	Mile point	Elev (ft)	Stream order	Width[a] (m)	Flow July 1966	pH	cold	hot	Total alkalinity	Total hardness
Doe Pond Outflow[b]	3.6	990	2nd		low	7.0	2	0	8	28
Unnamed stream[b]	3.6	990	1st	5	low	6.7	7	4	20	27
Doe Run[c]	3.6	990	1st	5	dry	7.1	3	3	3	26
Shaw Run[b]	3.7	990	1st	3	low	6.9	4	4	3	63
Pleasant Creek[d]	3.7	990	3rd	30	dry	6.3	5	4	8	257
Lick Run[e]	5.6	1010	2nd	6	dry	7.5	2	0	-	20
Sandy Creek[b]	6.4	1010	4th	50	low	3.3	177	178	-	145
Stoney Run[b]	8.7	1010	2nd	6	low	6.7	1	1	40	38
Tygart River[b]	9.5	1085	-	150	low	4.2	16	21	-	82

[a] Measured between high water marks

Sampling dates

[b] July 11 - 14, 1966

[c] June 14, 1967

[d] October 9, 1966

[e] August 8, 1967

Survey 7.5-minute Philippi Quandrangle shows extensive strip mine areas along the upper stream course. It seems evident that Pleasant Creek contributes mine drainage to Tygart Lake. However, the contribution was not acidic and therefore Pleasant Creek is not considered to be a source of acid water.

Sandy Creek, a fourth order stream, is with the exception of the Tygart River the largest stream entering the Reservoir. Table 7 shows it to be the most concentrated source of acid water with a low pH of 3.3, high total cold and hot acidities of 177 and 178 mg/liter, and high non-carbonate hardness of 145 mg/liter. This condition of extreme acidity appears to be one of long standing; Seaman and Stephens (1948) reported a range of pH 3.0 to 4.1 at the mouth of Sandy Creek for 1947-1948.

The Tygart River constitutes the main inflow of Tygart Lake. The acid concentration as indicated in Table 7 by a pH of 4.2 and total cold and hot acidities of 16 and 21 mg/liter do not show the extreme concentration of acid characteristic of Sandy Creek, but presumably this is compensated by a much greater discharge. The non-carbonate hardness of 82 mg/liter can be considered to primarily represent mine drainage in view of the low hardness characteristic of non-polluted waters in the upper basin.

Conclusions based on the survey of Tygart Lake tributaries are:

1. The small first and second order drainages entering the lake are presumed to be non-contributive as sources of acid water.
2. Pleasant Creek contributes mine drainage, but the contribution is not acidic.

3. The Tygart River and Sandy Creek constitute the only significant sources of acid water.

Water-Level Fluctuation and Flow Relationships

The Corps of Engineers operational plan calls for a gradual drawdown of Tygart Lake storage beginning about July 1 and continuing until the winter minimum pool is established about December 15. Except for temporary flood impoundment, the winter pool is maintained near elevation 1,101 feet from December 16 to the end of March. From April 1 to June 15, the excess inflow is impounded to establish the summer low-water regulation pool of 1,094 feet.

In Table 8 the effect of operational drawdown on lake depth is demonstrated by successive changes in monthly minimum lake depths from July through December in 1966 and in 1967. The net changes for both years were similar, with a decrease in depth of 47 feet (14 meters) in 1966 and 52 feet (16 meters) in 1967. The maximum net change related to drawdown was 72 feet (22 meters) from pool elevation 1091 feet in July 1966 to pool elevation 1019 feet in February 1967. This change corresponds approximately to the projected operational drawdown from 1094 feet at summer regulation pool to 1010 feet, the winter minimum pool, with a net decrease of 84 feet (26 meters).

Perhaps the most striking feature in Table 8 is the train of consequences associated with 1967 March and May precipitation totals which are approximately double the normal monthly precipitation values. In March the initial period of heavy precipitation, 3.8 inches, began on March 4 and continued through the morning of March 7. From March 4 to March 8 the pool level increased 123 feet (37.5 meters)

TABLE 8. Monthly ranges of regulated pool elevation and outflow, Tygart Lake, in relation to precipitation and inflow [a].

Year Month	Precipitation (inches)		Pool elevation (feet)		Lake depth at Dam (feet)		Inflow (cfs)		Outflow (cfs)	
	Total	Normal	Max	Min	Max	Min	Max	Min	Max	Min
1966										
Jul	3.92	4.82	1091	1084	129	122	1050	100	290	180
Aug	4.11	4.32	1089	1082	127	120	2550	100	830	180
Sep	5.48	3.49	1082	1071	120	109	4280	100	1300	500
Oct	2.34	2.78	1091	1064	129	102	8730	200	6050	800
Nov	3.54	2.88	1065	1052	103	90	8650	300	3910	800
Dec	2.91	3.14	1079	1037	117	75	9340	800	8400	1200
1967										
Jan	1.10	3.80	1046	1028	84	66	2420	600	3310	850
Feb	3.63	3.63	1042	1019	80	57	9000	1400	5210	1400
Mar	8.67	4.38	1151	1024	189	62	58600	3600	18500	120
Apr	3.76	4.10	1091	1051	129	89	6760	1000	2760	400
May	8.31	4.14	1145	1092	183	130	23000	700	18100	100

---

[a] Based on Monthly Reservoir Regulation hydrographs of the U. S. Army Corps of Engineers.

TABLE 8. Monthly ranges of regulated pool elevation and outflow, Tygart Lake, in relation to precipitation and inflow[a].

Year Month	Precipitation (inches)		Pool elevation (feet)		Lake depth at Dam (feet)		Inflow (cfs)		Outflow (cfs)	
	Total	Normal	Max	Min	Max	Min	Max	Min	Max	Min
1967										
Jun	1.96	5.29	1102	1092	140	130	650	100	3140	100
Jul	5.71	4.89	1102	1093	140	131	7010	100	3200	100
Aug	3.51	4.27	1102	1089	140	127	3550	80	3200	400
Sep	3.94	3.57	1094	1071	132	109	5580	10	786	640
Oct	3.49	2.78	1081	1071	119	109	7970	200	4320	700
Nov	2.87	2.87	1077	1056	115	94	7130	550	7060	700
Dec	5.09	3.31	1078	1041	116	79	15800	1250	9910	150

[a] Based on Monthly Reservoir Regulation hydrographs of the U. S. Army Corps of Engineers.

from a near winter minimum of 1028 feet to 1151 feet elevation at peak flood stage. A second maximum elevation of 1141 feet occurred on March 17 following another period of high precipitation. The maximum net change in lake depth during the 18 month period of investigation was 132 feet (40 meters) from the winter minimum of 57 feet (17 meters) on February 15 to 189 feet (58 meters) on March 8.

By the end of March outflow had reduced the pool elevation to 1050 feet. Precipitation in April was slightly below normal (Table 8); however, the pool elevation increased gradually to a maximum of 1091 feet on April 30. The increase was related to the operational plan for impoundment of excess inflow from April 1 to June 15 to establish the summer low water regulation pool at 1094 feet elevation.

In May 1967, the major part of the monthly precipitation of 8.3 inches was distributed over the 10-day period from May 6 to May 16. The pool elevation increased from 1094 feet on May 6 to an initial flood stage peak of 1127 feet on May 10. The maximum of 1145 feet elevation was reached in a second peak on May 17. Seven days later, May 24, drawdown had reduced the pool elevation to 1095 feet. Net turnover of flood storage for the 18 day period from May 6 to May 24 was approximately 112,000 acre-feet. This turnover is greater than the capacity of Tygart Lake at summer pool elevation of 1094 feet.

Changes in lake depth were least from June through August in relation to maintenance of the summer low-water regulation pool (Table 8). In 1966 lake depths ranged from 129 feet (39 meters) on July 1 to 120 feet (37 meters) on August 31. Summer lake levels were substantially higher in 1967. Depths ranged from 140 feet

(43 meters) recorded in June, July and August to a minimum of 127 feet (39 meters) on August 26. Rainfall was deficient during the summer in both 1966 and 1967. The higher summer pool in 1967 is accounted for by a lesser deficiency of 3.3 inches from June through August in 1967 compared with a deficiency of 4.5 inches for the same period in 1966.

In Table 9 the relationships shown by depths, inflows and outflows for the sequence of 32 cruises suggest division into contrasting seasonal periods reflecting water level fluctuations .

The summer pool consists of Cruises 1-3, July through August 1966 and Cruises 24-28, June through August 1967. This period is characterized by maintenance of relatively constant water levels and minimum inflows and outflows. This is the period of greatest stability with regard to depth and balance between outflow and inflow.

The autumn-winter drawdown begins in September (Cruise 4 in 1966; Cruise 29 in 1967) with a drop in water level of 4 to 5 meters. It is characterized by a continuing pattern of decreasing depths to the minimum winter pool level. In 1966, as shown in Table 9, the minimum depth was reached in January for Cruise 13. Table 8 lake depth data extend this period through February. In 1967 the drawdown period is terminated with Cruise 32 in December. In both years outflows were generally greater than those for the preceding summer pool periods. The drawdown period used here is extended beyond that given in the Corps of Engineers operational plan.

The spring pool has no Corps of Engineers operational equivalent except as it

TABLE 9. Physical parameters for selected cruises. Data reference is the deep-water 1-mile station except Cruises 1 and 2, 22 to 25, and 29 to 31 where the 0.5-mile station is used. Outlet depth refers to invert elevation.

Cruise		Elevation[a] (mean sea level)		Est[b] depth	Outlet depth	Daily[c] inflow	Daily[c] outflow
no	date	(ft)	(m)	(m)	(m)	(cfs)	(cfs)
	1966						
1	Jul 26	1084	330	36	28	21	273
2	Aug 4	1083	330	36	28	99	252
3	Aug 19	1088	332	38	38	1004	730
4	Sep 11	1075	328	34	26	15	507
5	Sep 24	1073	327	33	25	838	501
7	Oct 23	1068	326	31	24	855	792
9	Nov 20	1060	323	29	21	601	1255
11	Dec 19	1040	317	23	14	1295	2206
	1967						
13	Jan 29	1031	314	20	12	2187	892
16	Mar 12	1120	341	47	38	4175	16485
17	Mar 19	1125	343	49	40	5094	16833
18	Apr 1	1050	320	26	18	1382	1154
22	May 10	1127	344	49	40	12542	14090
23	May 12	1130	344	50	41	13273	6725
24	Jun 15	1095	334	40	32	185	273

[a] midday elevations from monthly reservoir hydrographs, U. S. Army Corps of Engineers

(Continued)

TABLE 9. Physical parameters for selected cruises. Data reference is the deep-water 1-mile station except Cruises 1 and 2, 22 to 25, and 29 to 31 where the 0.5-mile station is used. Outlet depth refers to invert elevation.

Cruise no	Cruise date	Elevation[a] (mean sea level) (ft)	Elevation[a] (mean sea level) (m)	Est[b] depth (m)	Outlet depth (m)	Daily[c] inflow (cfs)	Daily[c] outflow (cfs)
	1967						
25	Jun 28	1093	333	39	31	104	329
26	Jul 12	1093	333	39	31	1200	190
27	Jul 26	1096	334	40	32	420	390
28	Aug 15	1093	333	39	31	100	550
29	Sep 24	1075	328	34	26	40	650
30	Oct 22	1079	329	35	27	2000	1410
31	Nov 19	1056	322	28	20	690	700
32	Dec 10	1047	319	25	17	2900	3300

[a] midday elevations from monthly reservoir hydrographs, U. S. Army Corps of Engineers

[b] based on bottom contour elevation, 1959 sedimentation survey U. S. Army Corps of Engineers

[c] monthly operation summary, U. S. Corps of Engineers

corresponds with the function of flood storage during the winter minimum pool. In Table 9 the spring pool includes Cruises 16 through 23 extending from March through May. The period is characterized by extreme fluctuations in depth, inflow and outflow related to temporary storage of floodwater and subsequent drawdown.

Turbidity and Transparency

The U. S. Geological Survey turbidity tape was used under field conditions of varying light and surface disturbance by wave action. It is therefore likely that the turbidity data of Table 10 represent only approximations of the actual turbidity values. Even with this qualification, it appears that the main lake, the Pleasant Creek Arm, and the Sandy Creek Arm in general are characterized by low turbidity. Secchi Disk Transparency (Table 11), subject to the same limitations, also indicated relatively low turbidity and suggests high light transmission. The transparency values for the summer months are sufficiently great to infer a deficiency of phytoplankton in the surface layer. On this basis Tygart Lake could be tentatively classified as oligotrophic. Data for Doe Pond (Table 10) demonstrates the consistent presence of moderate amounts of turbidity. These values are consistently greater than most of the main lake turbidity values. Doe Pond, however could not be referred to a being muddy or turbid since its turbidity was in a relatively low range. Transparency values (Table 11) for Doe Pond agree with the turbidity data and suggest reduced light transmission. The lower transparency values did not appear to be generally related to suspension of inorganic particles. An inferency may be made that the difference in turbidity and transparency between Doe Pond and the main lake reflects greater abundance of plankton in Doe Pond.

TABLE 10. Surface turbidity in standard units. Field measurements made with a standard USGS turbidity tape.

Cruise		Lake			Pleasant	Sandy	Doe
No	Date	Inlet	5-mile	1-mile	Arm	Arm	Pond
1966							
1	Jul 26	<7	<7	<7	<7	28^{a}	26
2	Aug 4	<7	<7	<7	<7	<7	30
3	Aug 19	26	<7			<7	18
4	Sep 11		<7	<7	<7	<7	
5	Sep 24	<7	<7	<7	<7	<7	
7	Oct 23	$<7^{b}$	$<7^{b}$	$<7^{b}$	$<7^{b}$	$<7^{b}$	35
9	Nov 20		<7	$<7^{b}$		$<7^{b}$	22
11	Dec 19		<7	<7	<7	16	20
1967							
13	Jan 29	Ice	Ice	<7	Ice	Ice	
16	Mar 12	<7		115			
17	Mar 19	<7	70				
18	Apr 1		<7	<7			
22	May 10	45	<7	$<7^{c}$			
23	May 12	70	<7	$<7^{c}$			
24	Jun 15	<7	<7	<7	<7	<7	20
25	Jun 28	<7	<7	<7	<7	<7	35
26	Jul 12	<7	<7	$<7^{c}$	<7	<7	
27	Jul 26	12	<7	$<7^{c}$	<7	<7	16

[a] Probably erroneous; based on the corresponding transparency a turbidity value of 7 units would be expected.

[b] Estimated reading of 7 units based on corresponding transparency of 1,5 meters or more.

[c] Turbidity of the 0.5-mile station substituted.

TABLE 10(Continued)

Cruise		Lake			Pleasant	Sandy	Doe
No	Date	Inlet	5-mile	1-mile	Arm	Arm	Pond
28	Aug 15	<7	<7	$<7^{c}$	<7		20
29	Sep 24	20	<7	$<7^{c}$	<7	<7	30
30	Oct 22		$<7^{b}$	$<7^{bc}$	$<7^{b}$	$<7^{b}$	
31	Nov 19		$<7^{b}$	$<7^{bc}$	$<7^{b}$	$<7^{b}$	
32	Dec 10		$<7^{b}$	$<7^{b}$	$<7^{b}$		

TABLE 11. Secchi disk transparency in meters.

Cruise No.	Date	Inlet	5-mile	1-mile	Pleasant Arm	Sandy Arm	Doe Pond
1966							
1	Jul 26	1.8	3.3	4.8	4.5	3.5	0.5
2	Aug 4	2.5	5.6	5.8	4.5	4.0	0.8
3	Aug 19	0.6	5.4			2.5	0.8
4	Sep 11		4.0	3.8	3.8	3.5	
5	Sep 24	1.6	3.0	4.2		2.4	0.2
7	Oct 23	1.5	4.4	6.0	4.4	3.5	0.2
9	Nov 20		7.0	7.1		6.7	0.3
11	Dec 19	0.4	2.3	5.5	3.0	0.5	3.0
1967							
13	Jan 29	Ice	Ice	3.8	Ice	Ice	1.7
16	Mar 12	5.7					
17	Mar 19	2.3					
18	Apr 1		5.0	3.5			
22	May 10	0.2	2.8	3.0[a]			
23	May 12	0.5	1.9	3.1[a]			
24	Jun 15	7.5	6.0	2.8	4.4	7.0	0.2
25	Jun 28	2.9	4.7	4.6	4.0	5.0	0.2
26	Jul 12	3.2	3.5	3.5[a]	3.4	3.8	0.2
27	Jul 26	1.2	3.4	4.5[a]	4.0	2.7	0.5
28	Aug 15	1.6	3.5	5.0[a]	3.0	2.3	0.6

[a] Transparency of the 0.5-mile station substituted.

TABLE 11. (Continued)

Cruise					Pleasant Arm	Sandy Arm	Doe Pond
No.	Date	Inlet	5-mile	1-mile			
29	Sep 24	2.0	3.0	2.6[a]	3.0	2.3	0.6
30	Oct 22	0.4	4.0	4.9[a]	3.8	2.8	0.4
31	Nov 19	0.7	1.5	3.5[a]	2.8	2.3	0.1
32	Dec 10	0.1	2.3	1.6	1.8	0.6	0.3

The isolated instances of higher turbidity values in the main lake (Table 10) are associated with peak inflows. Moderately turbid surface water is evident at the lake inlet in Cruise 3. A possible explanation of the low surface turbidity at the 5-mile station in the same cruise is that the turbid water is moving into the lake as a density current. A similar pattern is indicated by the data for Cruises 22, 23, 27 and 29 Table 10. A reversal of this sequence appears in Cruises 16 and 17 where the inlet water is relatively clear in contrast with high turbidities at the 5-mile and 1-mile stations.

Ice Cover

An ice cover was present on Tygart Lake recurrently during the winter of 1966-1967. Freezing was first encountered on December 4, 1966 (Cruise 10); a thin ice cover up to 0.5 inches thick was present on the main lake between the 5-mile and 7-mile points. The remainder of the lake was ice free. The lake was completely open on December 19 (Cruise 11) except for a rim of thin ice along the shoreline. On January 14 the lake was completely covered by 1 to 2 inches of ice. The 12-mile river station was the only ice free area. The main lake was again briefly open and ice free on January 28, 1967 (Cruise 13). Complete freezing followed, and a thick ice cover was present throughout February (February 11, Cruise 14; February 25, Cruise 15), except at the 12-mile river station.

Treatment of Results for Temperature and Water Chemistry

Tabular results for sampling elevations, temperature and water chemistry are presented in Tables 12-1 through 19-3. In addition temperature and pH profiles are submitted in Figures 5 through 13 for the Lower Lake station (0.5-mile and 1.0-mile sites).

TABLE 12-1. Reference elevations (meters) for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 37	a 36	b 34	c 32	c 29	b 24	d 20	21	a 50
Lake Inlet	S1	a 37	a 36	b 34	c 32	c 29	b 24	.	.	a 50
	S2	33	33	32	29	28	21	.	.	42
Upper Lake	S1	a 37	a 36	a 34	a 32	a 29	a 24	.	.	a 47
	S2	31	32	28	28	26	22	.	.	40
	S3	b 28	28	24	24	22	20	.	.	b 35
	S4	25	b 24	20	b 19	19	17	.	.	29
	S4-1	19	18	17	c 17	b 16	15	.	.	22
	S5	c 14	c 14	b 15	14	15	14	.	.	13
Lower Lake	S1	a 36	a 36	a 34	a 32	a 29	c 23	a 20	.	a 47
	S2	33	31	30	28	26	21	19	.	42
	S3	b 26	26	25	24	23	19	17	.	b 34
	S4	21	b 24	20	20	19	16	16	.	26
	S4-1	18	18	17	b 17	16	15	15	.	24
	S5	c 14	14	15	14	14	14	14	.	13
	0	9	c 10	b 7	12	b 10	5	b 7	.	10
	B	0	1	c 2	c 4	5	1	c 1	.	2

TABLE 12-1 Reference elevations (meters) for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 26	b 50	a 40	a 40	b 39	b 34	c 35	d 28	a 26
Lake Inlet	S1	a 26	b 50	a 40	a 40	a 39	b 34	c 35	d 28	a 26
	S2	23	45	b 37	35	b 34	32	30	26	24
	S3	.	35	32	33	.	.	37	.	.
Upper Lake	S1	a 26	a 50	a 40	a 40	a 39	a 34	a 35	c 28	a 26
	S2	23	45	b 35	35	34	29	30	25	24
	S3	b 21	b 35	30	30	29	24	25	23	21
	S4	18	29	c 25	b 25	b 24	19	b 20	18	18
	S4-1	16	20	20	20	19	17	17	16	16
	S5	14	15	15	c 14	13	13	c 13	15	13
Lower Lake	S1	a 26	a 50	a 40	a 40	a 39	a 34	a 35	a 28	a 25
	S2	b 24	b 45	b 35	35	34	29	30	25	23
	S3	21	35	30	b 30	29	24	25	23	b 20
	S4	19	30	c 25	25	b 24	19	b 20	18	c 17
	S4-1	16	20	20	20	19	17	17	b 16	16
	S5	15	15	15	15	14	14	15	13	15
	0	c 10	10	10	c 10	9	9	c 10	c 8	10
	B	3	0	0	0	c 0	c 0	0	0	8

TABLE 12-2. Reference elevations (meters) for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 34	c 32	c 29	b 24	.	20	50
Sandy Inlet	S1	a 37	a 36	a 34	c 32	c 29	b 24	.	.	.
	S2	b 32	32	b 31	31	27	21	.	.	.
Sandy Arm	S1	a 37	a 36	a 34	a 32	a 29	a 24	.	.	.
	S2	33	31	30	28	26	.	.	.	.
	S3	b 28	b 26	27	26	b 21	.	.	.	.
	S4	23	21	20	b 21	20	.	.	.	.
Pleasant Creek	S1	.	.	.	c 32	c 29	a 24	20	21	47
Pleasant Inlet	S1	a 37	a 36	a 34	b 32	b 29	a 24	.	.	.
	S2	34	32	b 32	30	c 27	.	.	.	.
Pleasant Arm	S1	a 37	a 36	a 34	a 32	a 29	a 24	.	.	.
	S2	32	31	30	28	26	22	.	.	.
	S3	b 28	27	24	24	22	20	.	.	.
	S4	22	b 20	20	20	19	17	.	.	.
	S4-1	18	17	17	17	16	15	.	.	.
	S5	c 14	13	14	b 14	b 14	14	.	.	.

TABLE 12-2. Reference elevations (meters) for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	26	50	a 40	b 40	b 39	b 34	c 35	d 28	a 26
Sandy Inlet	S1	.	.	a 40	a 40	a 39	a 34	a 35	d 28	.
	S2	.	.	b 35	35	b 34	b 31	b 32	26	.
Sandy Arm	S1	.	.	a 40	a 40	a 39	a 34	a 35	a 28	a 26
	S2	.	.	b 35	35	34	29	30	25	24
	S3	.	.	30	b 30	29	24	b 25	b 23	21
	S4	.	.	25	25	b 24	22	22	c 20	.
	S4-1	.	.	c 20	21	19	.	.	.	.
Pleasant Creek	S1	26	50	a 40	b 40	b 39	b 34	c 35	c 28	a 26
Pleasant Inlet	S1	.	.	a 40	a 40	a 39	a 34	a 35	c 28	a 26
	S2	.	.	39	39	b 38	32	b 32	27	24
Pleasant Arm	S1	.	.	a 40	a 40	a 39	a 34	a 35	a 28	a 26
	S2	.	.	b 35	35	34	29	30	25	24
	S3	.	.	30	b 30	29	24	25	23	b 21
	S4	.	.	c 25	25	b 24	19	b 20	18	c 18
	S4-1	.	.	20	20	19	17	16	16	16
	S5	.	.	13	c 13	13	14	c 12	b 13	13

TABLE 12-3. Reference depths for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 0.5	a 0.5	a 0.5	a 0.5	b 0.5	a 0.5	a 0.5	a 0.5	0.5
Lower Pond	D1	a 0.5	a 0.5	a 0.5	a 0.5	a 0.5	a 0.5	a 0.5	a 0.5	.
	D2	b 2.0	b 2.0	2.5	2.4	2.0	2.0	2.0	.	.
	D3	c 3.2	c 3.0	.	.	3.5	3.0	3.0	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 0.5	a 0.5	a 0.0	a 0.0	a 0.0	a 0.0	a 0.0	a 0.0
	D2	2.0	b 2.0	b 2.0	b 2.0	1.0	1.0	2.0	2.0
	D3	4.0	c 4.0	c 4.0	3.0	b 4.0	3.0	4.0	4.0

TABLE 13-1. Reference temperatures (Celsius) for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 26.4	a 25.0	b 19.6	c 9.6	c 5.8	b 3.0	d 4.0	0.0	a 6.5
Lake Inlet	S1	a 27.0	a 24.8	b 21.2	c 8.8	c 6.0	b 2.5	.	.	a 5.8
	S2	25.5	24.5	20.2	8.8	6.0	2.5	.	.	5.2
Upper Lake	S1	a 26.4	a 25.0	a 23.5	a 14.0	a 9.2	a 1.8	.	.	a 6.6
	S2	25.9	25.0	23.2	13.8	9.2	1.8	.	.	5.4
	S3	b 22.6	25.0	23.0	13.8	9.0	1.8	.	.	b 5.0
	S4	20.0	b 21.6	23.0	b 13.2	9.0	1.8	.	.	4.8
	S4-1	16.5	18.5	22.8	c 10.0	b 7.6	1.8	.	.	4.6
	S5	c 15.0	c 16.0	b 22.2	9.8	6.6	1.8	.	.	4.2
Lower Lake	S1	a 26.2	a 25.2	a 23.5	a 14.0	a 9.2	c 4.0	a 0.5	.	a 6.6
	S2	26.0	24.5	23.0	14.0	9.2	4.0	0.5	.	5.8
	S3	b 22.8	24.5	23.2	14.0	9.2	4.0	0.5	.	b 4.8
	S4	19.8	b 21.5	23.0	14.0	9.2	4.0	0.5	.	4.8
	S4-1	17.8	18.4	23.0	b 13.6	9.0	4.0	0.5	.	4.4
	S5	c 15.8	16.4	23.0	13.2	9.0	4.0	0.5	.	4.2
	O	14.8	c 15.0	b 20.0	13.0	b 7.5	3.8	b 1.6	.	4.0
	B	12.0	12.0	c 11.2	c 11.0	6.8	3.8	c 2.2	.	4.0

TABLE 13-1. Reference temperatures (Celsius) for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 16.0	b 11.2	a 29.0	a 24.4	b 22.8	b 18.0	c 10.4	d 4.4	a 5.0
Lake Inlet	S1	a 16.2	b 11.4	a 28.8	a 25.0	a 25.0	b 19.8	c 10.4	d 4.4	a 5.0
	S2	16.0	11.2	b 23.0	24.8	b 22.2	18.0	10.4	4.4	5.0
	S3	.	11.2	18.8	24.2	.	.	10.4	.	.
Upper Lake	S1	a 14.8	a 13.0	a 27.0	a 25.8	a 25.6	a 22.2	a 17.6	c 5.4	a 5.0
	S2	14.0	12.8	b 22.0	25.0	24.6	22.0	17.0	5.4	5.0
	S3	b 13.5	b 11.8	18.0	24.0	24.4	22.0	16.8	5.2	5.0
	S4	12.0	11.2	c 16.0	b 21.2	b 22.8	22.0	b 16.0	5.2	5.0
	S4-1	10.2	10.4	15.0	18.0	21.6	22.0	11.8	5.2	5.0
	S5	8.8	10.0	14.2	c 15.8	20.2	21.8	c 11.0	5.0	5.0
Lower Lake	S1	a 15.0	a 13.4	a 27.0	a 25.2	a 25.2	a 22.0	a 17.2	a 9.0	a 5.0
	S2	b 13.0	b 12.2	b 23.4	25.0	24.8	22.0	17.0	9.0	4.8
	S3	12.5	11.2	18.4	b 23.2	24.4	22.2	17.0	9.0	b 4.6
	S4	11.2	11.0	c 16.2	21.6	b 23.0	22.0	b 16.0	8.8	c 4.0
	S4-1	9.5	10.4	15.0	18.8	21.8	22.0	15.2	b 8.0	4.0
	S5	8.5	10.2	14.2	16.0	21.0	22.0	14.0	8.0	4.0
	O	c 7.0	10.2	13.6	c 15.0	20.0	22.0	c 12.2	c 7.0	4.0
	B	6.5	10.0	11.2	11.4	c 11.6	c 12.2	12.0	6.8	4.0

TABLE 13-2. Reference temperatures (Celsius) for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 18.0	c 9.2	c 5.0	b 4.0	.	1.5	7.5
Sandy Inlet	S1	a 25.5	a 25.6	a 23.5	c 11.2	c 5.8	b 4.0	.	.	.
	S2	b 24.4	24.6	b 21.5	10.0	5.2	4.0	.	.	.
Sandy Arm	S1	a 25.8	a 25.0	a 23.5	a 13.8	a 9.2	a 2.5	.	.	.
	S2	25.8	24.8	23.2	13.8	9.2	.	.	.	.
	S3	b 23.0	b 23.8	23.0	13.8	b 8.8	.	.	.	.
	S4	19.8	20.8	22.5	b 12.8	8.6	.	.	.	.
Pleasant Creek	S1	.	.	.	c 6.4	c 4.5	a 3.8	3.6	0.8	8.0
Pleasant Inlet	S1	a 27.0	a 26.2	a 23.0	b 13.2	b 8.4	a 4.0	.	.	.
	S2	26.5	25.4	b 21.5	11.4	c 5.0	.	.	.	.
Pleasant Arm	S1	a 26.0	a 25.6	a 23.2	a 13.8	a 9.2	a 4.0	.	.	.
	S2	25.2	24.8	23.0	13.8	9.2	4.0	.	.	.
	S3	b 22.8	24.6	23.0	13.8	9.0	4.0	.	.	.
	S4	19.0	b 20.0	23.0	13.8	9.0	3.8	.	.	.
	S4-1	16.5	18.0	22.8	13.8	9.0	3.4	.	.	.
	S5	c 14.8	16.8	22.8	b 13.4	b 7.4	3.4	.	.	.

TABLE 13-2. Reference temperatures (Celsius) for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise sereis 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	16.2	11.8	a 27.0	b 22.8	b 20.8	b 18.0	c 9.6	d 4.8	a 4.8
Sandy Inlet	S1	.	.	a 28.6	a 25.6	a 25.2	a 22.0	a 16.8	d 4.9	.
	S2	.	.	b 22.2	24.4	b 22.6	b 20.0	b 10.8	4.8	.
Sandy Arm	S1	.	.	a 27.8	a 25.4	a 25.0	a 22.2	a 17.2	a 7.0	a 4.8
	S2	.	.	b 21.0	25.0	24.6	22.0	17.2	6.8	4.8
	S3	.	.	18.0	b 23.8	24.2	22.0	b 16.0	b 6.4	4.8
	S4	.	.	16.0	21.2	b 22.8	21.8	b 11.2	6.2	.
	S4-1	.	.	c 15.0	19.0	21.6	.	.	.	.
Pleasant Creek	S1	16.0	14.0	a 29.0	b 22.0	b 21.0	b 21.0	c 11.8	c 5.4	a 5.0
Pleasant Inlet	S1	.	.	a 27.0	a 25.2	a 24.6	a 22.0	a 17.2	c 5.4	a 5.0
	S2	.	.	26.4	25.0	b 24.0	22.0	b 16.4	5.4	5.0
Pleasant Arm	S1	.	.	a 26.6	a 25.2	a 24.8	a 22.0	a 17.6	a 9.0	a 5.0
	S2	.	.	b 23.2	25.0	24.6	21.8	17.4	9.0	4.8
	S3	.	.	18.2	b 23.6	24.4	21.8	17.2	9.0	b 4.2
	S4	.	.	c 16.0	21.2	b 23.0	21.8	b 16.6	9.0	c 4.0
	S4-1	.	.	15.0	18.6	21.8	21.6	14.0	9.0	4.0
	S5	.	.	13.8	c 15.4	20.4	21.4	c 11.8	b 8.7	4.0

TABLE 13-3. Reference temperatures (Celsius) for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 25.2	a 25.5	a 15.2	a 8.5	b 6.0	a 3.0	a 4.8	a 0.7	8.0
Lower Pond	D1	a 25.8	a 25.5	a 15.5	a 8.8	a 7.0	a 3.0	a 4.8	a 0.7	.
	D2	b 22.2	b 23.2	15.2	8.8	7.0	3.0	4.8	.	.
	D3	c 15.0	c 16.8	.	.	7.0	3.0	4.4	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 15.4	a 32.8	a 27.4	a 25.0	a 21.6	a 13.4	a 5.6	a 4.8
	D2	15.0	b 24.0	b 24.4	b 22.0	20.6	13.2	5.7	4.9
	D3	15.0	c 15.0	c 21.4	21.8	b 18.4	13.2	5.6	4.9

TABLE 14-1. Dissolved oxygen (mg/liter), values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 8	a 8	b 9	c 10	c 11	b 12	d .	.	a 11
Lake Inlet	S1	a 7	a 8	b 8	c 10	c 6	b 11	.	.	a 12
	S2	7	8	9	11	11	11	.	.	12
Upper Lake	S1	a 8	a 8	a 7	a 8	a 11	a 11	.	.	a 10
	S2	.	7	7	.	.	.	.	.	9
	S3	b .	7	7	.	11	.	.	.	b .
	S4	.	b 6	.	b 9	.	.	.	.	10
	S4-1	.	6	7	c .	b .	.	.	.	11
	S5	c 3	c 1	b 7	8	11	.	.	.	12
Lower Lake	S1	a 8	a 8	a 8	a 8	a 11	c 10	a 13	.	a .
	S2	.	8	.	.	.	.	.	.	.
	S3	b 9	8	.	.	.	.	.	.	b .
	S4	9	b 9	.	.	.	.	.	.	12
	S4-1	.	8	.	b .	.	.	.	.	12
	S5	c .	8	.	.	.	.	.	.	.
	0	7	c 7	b 1	8	b 10	12	b 13	.	.
	B	1	2	c 0	c 8	10	12	c 12	.	12

TABLE 14-1. Dissolved oxygen (mg/liter), values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a .	b .	a 7	a 8	b 8	b 8	c 11	d 8	a 7
Lake Inlet	S1	a 9	b .	a 7	a 8	a 8	b 7	c 10	d 9	a 7
	S2	9	.	b .	7	b 7	7	11	8	.
	S3	.	.	8	.	.	.	11	.	.
Upper Lake	S1	a 9	a	a 8	a 8	a 7	a 7	a 6	c 10	a 6
	S2	.	.	b 9	8	8	7	6	.	.
	S3	b .	b .	10	7	7	.	6	9	7
	S4	9	.	c 10	b 8	b 7	6	b 4	8	
	S4-1	.	.	9	8	7	.	6	.	8
	S5	10	.	8	c 3	.	5	c 7	7	5
Lower Lake	S1	a 10	a .	a 8	a 7	a 8	a 7	a 5	a 6	a 8
	S2	b .	b .	b 9	8	8	7	5	.	.
	S3	.	.	10	b 9	7	7	5	7	b 6
	S4	.	.	c 10	8	b 7	7	b 5	7	c .
	S4-1	.	.	9	9	7	.	.	b .	.
	S5	12	.	9	9	6	7	6	7	5
	O	c 12	.	9	c 8	4	7	c 6	c 7	6
	B	11	.	5	1	c .2	c 6	6	.	7

TABLE 14-2. Dissolved oxygen (mg/liter), values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 7	c 10	c 11	b 10	.	.	12
Sandy Inlet	S1	a 8	a 8	a 7	c 10	c 11	b 10	.	.	.
	S2	b 8	7	b 7	.	.	11	.	.	.
Sandy Arm	S1	a 8	a 8	a 7	a 9	a 10	a 11	.	.	.
	S2	.	8	.	.	.	.	.	.	.
	S3	b 8	b 6	7	9	b 10	.	.	.	.
	S4	5	0.5	6	b 9	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c 11	c 14	a 11	12	.	9
Pleasant Inlet	S1	a 8	a 8	a 8	b 8	b 11	a .	.	.	.
	S2	.	8	b 8	.	c 11	.	.	.	.
Pleasant Arm	S1	a 8	a 8	a 8	a 9	a 10	a 11	.	.	.
	S2	.	8	.	.	.	.	.	.	.
	S3	b 8	8	7	.	10	.	.	.	.
	S4	.	b 8	.	.	.	.	.	.	.
	S4-1	.	6	.	.	.	.	.	.	.
	S5	c 6	4	8	b 8	b 10	10	.	.	.

TABLE 14-2. Dissolved oxygen (mg/liter), values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	.	.	a 7	b 8	b 8	b 7	c 7	d 7	a 7
Sandy Inlet	S1	.	.	a 8	a 7	a 8	a 7	a 6	d 10	.
	S2	.	.	b 7	7	b 8	b 8	b 7	8	.
Sandy Arm	S1	.	.	a 7	a 8	a 8	a 7	a 6	a 8	a 6
	S2	.	.	b 9	8	8	7	6	.	.
	S3	.	.	9	b 7	7	8	b 6	b 7	6
	S4	.	.	9	6	b 4	7	4	c 8	.
	S4-1	.	.	c 8	5	2	.	.	.	.
Pleasant Creek	S1	.	.	a 7	b 7	b 8	b 5	c 10	c 10	a 6
Pleasant Inlet	S1	.	.	a 7	a 6	a 7	a 8	a 6	c 11	a 6
	S2	.	.	7	8	b 7	.	b 6	10	7
Pleasant Arm	S1	.	.	a 8	a 8	a 7	a 8	a 6	a 10	a 8
	S2	.	.	b 8	8	8	8	6	.	.
	S3	.	.	9	b 8	6	7	6	.	b 6
	S4	.	.	c 9	6	b 6	8	b 9	9	c .
	S4-1	.	.	9	8	7	.	.	.	8
	S5	.	.	8	c 5	4	7	c 6	b 7	6

TABLE 14-3. Dissolved oxygen (mg/liter), values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 8	a 8	a 8	a 9	b 7	a 12	a 11	a 12	10
Lower Pond	D1	a 8	a 8	a 8	a 10	a 11	a 10	a 11	a 12	.
	D2	b .	b 7	8	9	.	.	.	.	.
	D3	c 3	c 1	.	.	10	12	11	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 10	a 8	a 7	a 8	a 8	a 10	a 12	a 6
	D2	.	b 7	b 8	b .	8	10	11	7
	D3	10	c 1	c 3	4	b 7	10	8	8

TABLE 15-1. pH values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 3.9	a 3.4	b 4.4	c 6.6	c 6.4	b 5.3	d 5.9	5.7	a 5.4
Lake Inlet	S1	a 4.0	a 3.7	b 4.4	c 4.4	a 6.2	b 5.5	.	.	a 5.5
	S2	4.0	3.7	4.4	6.7	6.3	5.4	.	.	5.5
Upper Lake	S1	a 4.2	a 4.0	a 4.1	a 4.5	a 5.0	a 5.0	.	.	a 6.0
	S2	4.1	4.3	4.2	.	.	.	.	.	5.2
	S3	b .	4.2	4.1	.	4.9	.	.	.	b .
	S4	4.2	b 4.1	.	b 4.6	.	.	.	.	5.1
	S4-1	4.3	4.5	4.0	c .	b .	5.1	.	.	5.0
	S5	c 4.5	c 4.9	b 4.5	6.3	6.0	.	:	.	6.5
Lower Lake	S1	a 4.5	a 4.4	a 4.0	a 4.5	a 5.0	c 5.7	a 5.0		a 6.2
	S2	4.6	4.4	.	.	.	.	.	.	.
	S3	b 4.6	4.5	.	.	.	.	.	.	b 5.2
	S4	4.6	b 4.6	.	.	.	.	.	.	5.5
	S4-1	4.7	4.7	.	b .	.	.	.	.	5.5
	S5	c .	4.6	4.0	.	.	.	.	.	5.1
	O	4.8	c 4.8	b 4.8	4.5	b 6.1	5.7	b 5.0	.	
	B	5.3	5.3	c 5.9	c 4.6	6.1	5.8	c 5.0	.	6.1

TABLE 15-1. pH values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 4.5	b 6.4	a 4.6	a 7.7	b 4.6	b 4.6	c 7.1	d 5.5	a 6.7
Lake Inlet	S1	a 4.5	b 6.5	a 4.6	a 7.3	a 4.8	b 4.8	c 6.8	d 5.3	a 6.8
	S2	4.5	6.7	b 4.8	5.8	b 4.8	4.8	7.0	5.2	6.8
	S3	.	6.9	5.5	5.3	.	.	7.2	.	.
Upper Lake	S1	a 4.3	a 5.4	a 4.7	a 4.4	a 4.4	a 4.6	a 4.6	c 4.7	a 6.1
	S2	4.4	5.4	b 4.7	4.4	4.6	4.7	4.6	.	.
	S3	.	b 6.6	4.9	4.4	4.5	4.7	4.7	4.8	6.3
	S4	4.4	7.4	c 5.0	b 5.0	b 4.6	4.7	b 4.8	5.0	.
	S4-1	.	7.4	5.2	5.0	5.0	.	6.2	.	6.4
	S5	4.6	7.1	5.2	c 5.8	5.5	4.7	c 7.0	4.9	6.5
Lower Lake	S1	a 4.5	a 5.3	a 4.8	a 4.7	a 4.5	a 4.6	a 4.6	a 4.8	a 5.9
	S2	b .	b 5.3	b 5.0	4.7	4.5	4.6	4.7	.	.
	S3	.	6.2	5.0	b 4.5	4.5	4.7	4.7	4.8	b 6.1
	S4	4.6	5.3	c 5.2	4.8	b 4.5	4.8	b 4.6	4.8	c .
	S4-1	.	7.0	5.2	5.0	4.7	.	4.9	b .	.
	S5	4.7	7.2	5.3	5.3	4.7	4.7	5.0	4.8	5.9
	0	c 4.7	7.1	5.3	c 5.5	5.0	4.6	c 7.0	c 4.8	6.4
	B	4.6	7.2	5.5	5.8	c 5.6	c 4.8	6.2	4.8	6.3

TABLE 15-2. pH values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 3.4	c 3.6	c 3.6	b 3.7	.	4.7	4.5
Sandy Inlet	S1	a 4.2	a 4.0	a 4.2	c 3.7	c 3.6	b 6.6	.	.	.
	S2	b 3.8	3.9	b 4.1	.	.	3.7	.	.	.
Sandy Arm	S1	a 4.2	a 4.1	a 4.4	a 4.6	a 4.8	a 4.3	.	.	.
	S2	4.2	4.1	.	.	.	.	.	.	.
	S3	b 4.3	b 3.9	4.2	4.5	b 4.3	.	.	.	.
	S4	4.3	4.3	4.1	b 4.3	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c 6.2	c 6.2	a 6.7	6.4	7.2	6.3
Pleasant Inlet	S1	a 4.4	a 4.4	a 4.0	b 4.5	b 4.7	a 6.5	.	.	.
	S2	.	4.3	b 4.0	.	c 4.8	.	.	.	.
Pleasant Arm	S1	a 4.4	a 4.1	a 3.9	a 4.5	a 4.8	a 6.0	.	.	.
	S2	.	4.2	.	.	.	.	.	.	.
	S3	b 4.4	4.2	4.0	.	4.7	.	.	.	.
	S4	.	b 4.3	.	.	.	.	.	.	.
	S4-1	.	4.2	.	.	.	.	.	.	.
	S5	c 4.7	4.5	4.0	b 4.5	b 4.8	5.8	.	.	.

TABLE 15-2. pH values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	3.5	4.2	a 3.2	b 3.2	b 3.1	b 3.3	c 4.1	d 3.4	4.1
Sandy Inlet	S1	.	.	a 4.2	a 4.4	a 4.4	a 4.6	a 4.6	d 4.3	.
	S2	.	.	b 3.9	3.7	b 3.7	b 4.7	b 4.3	3.9	.
Sandy Arm	S1	.	.	a 4.5	a 4.5	a 4.5	a 4.8	a 4.6	d 4.1	a 4.1
	S2	.	.	b 4.3	4.1	4.6	4.6	4.6	.	.
	S3	.	.	4.9	b 4.1	4.5	4.7	b 4.4	b 4.3	4.1
	S4	.	.	4.9	5.2	b 4.8	4.6	5.4	c 3.9	.
	S4-1	.	.	c 4.9	5.8	5.4	.	.	.	.
Pleasant Creek	S1	6.3	7.5	a 7.5	b 7.4	b 7.4	b 6.8	c 7.0	c 7.2	a 6.9
Pleasant Inlet	S1	.	.	a 5.6	a 4.6	a 4.6	a 4.6	a 4.6	c 7.2	a 7.0
	S2	.	.	5.8	4.7	b 5.0	4.7	b 4.7	7.1	7.1
Pleasant Arm	S1	.	.	a 4.9	a 4.6	a 4.5	a 4.6	a 4.6	a 4.9	a 5.6
	S2	.	.	b 5.0	4.6	4.5	4.7	4.6	.	5.8
	S3	.	.	5.2	b 4.6	4.5	4.7	4.6	5.0	b 6.3
	S4	.	.	c 5.6	5.2	b 4.7	4.7	b 4.6	4.9	c .
	S4-1	.	.	5.6	5.1	5.0	.	5.4	.	6.5
	S5	.	.	5.7	c 5.7	5.4	4.7	c 4.7	b 4.9	6.3

TABLE 15-3. pH values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 6.6	a 6.2	a 6.5	a 6.7	b 6.4	a 6.7	a 6.3	a 6.6	7.1
Lower Pond	D1	a 6.5	a .	a 6.5	a 6.8	a 6.4	a 6.6	a 6.2	a 7.0	.
	D2	b	b 6.3	6.5	6.6	.	.	.	.	.
	D3	c 6.5	c 6.5	.	.	6.4	6.7	6.0	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 6.5	a 7.4	a 6.7	a 6.1	a 7.0	a 7.3	a 7.1	a 7.1
	D2	.	b 6.8	b 6.4	b 6.1	6.9	6.8	7.2	6.9
	D3	6.6	c 6.6	c 6.4	6.0	b 6.7	7.2	7.7	7.0

TABLE 16-1. Cold Acidity (mg/liter $CaCO_3$), values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 24	a 59	b 14	c 3	c 1	c 6	d 3	4	a 15
Lake Inlet	S1	a 26	a 52	b 11	c 9	c 2	b 5	.	.	a 20
	S2	27	61	14	5	2	5	.	.	14
Upper Lake	S1	a 17	a 13	a 11	a 8	a 4	a 8	.	.	a 4
	S2	13	14	12	.	.	.	.	.	9
	S3	b .	28	16	.	5	.	.	.	b .
	S4	13	b 16	.	b 7	.	.	.	.	10
	S4-1	17	16	12	c .	b .	.	.	.	16
	S5	c 20	c 21	b 10	1	2	6	..	.	6
Lower Lake	S1	a 13	a 10	a 11	a 5	a 4	c 4	a 8	.	a 3
	S2	10	9	.	.	.	.	.	.	b 4
	S3	b 10	10	.	.	.	.	.	.	3
	S4	10	b 9	.	.	.	.	.	.	4
	S4-1	7	9	.	b .	.	.	.	.	4
	S5	c .	10	14	.	.	.	.	.	
	O	11	c 8	b 12	9	b 3	2	b 9		2
	B	17	11	c 31	c 9	3	3	c 9	.	

TABLE 16-1. Cold Acidity (mg/liter Ca CO_3), values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 17	b 2	a 12	a 1	b 8	b 13	c 2	d 4	a 4
Lake Inlet	S1	a 16	b 2	a 10	a 4	a 8	b 10	c 3	d 5	a 4
	S2	13	2	b 8	4	b 8	10	3	5	5
	S3	.	3	7	8	.	.	3	.	.
Upper Lake	S1	a 15	a 4	a 5	a 9	a 11	a 8	a 8	c 9	a 4
	S2	16	5	b 5	9	10	8	8	.	.
	S3	b .	b 3	5	11	10	12	7	8	3
	S4	13	2	c 5	b 6	b 9	9	b 7	7	
	S4-1	.	2	4	5	6	.	3	.	4
	S5	10	2	4	c 11	8	10	c 4	7	4
Lower Lake	S1	a 11	a 4	a 5	a 6	a 11	a 13	a 8	a 4	a 4
	S2	b .	b 5	b 4	7	11	9	8	.	.
	S3	.	4	4	b 10	11	8	8	5	b 4
	S4	8	4	c 4	5	b 11	8	b 7	6	c .
	S4-1	.	2	3	4	8	.	7	b .	.
	S5	8	2	4	4	8	9	8	6	4
	0	c 10	2	4	c 4	6	9	c 3	c18	4
	B	9	2	9	11	c 8	c 9.	3	6	4

TABLE 16-2. Cold Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 102	c 53	c 44	b 48	.	34	55
Sandy Inlet	S1	a 14	a 19	a 12	c 39	c 43	b .	.	.	.
	S2	b 42	28	b 15	.	.	47	.	.	.
Sandy Arm	S1	a 20	a 18	a 12	a 11	a 6	a 15	.	.	.
	S2	18	19	.	.	.	.	.	.	.
	S3	b 12	b 24	13	6	b .	.	.	.	.
	S4	14	17	15	b 13	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c 4	c 2	a 3	2	2	3
Pleasant Inlet	S1	a 11	a 13	a 13	b 8	b 6	a 3	.	.	.
	S2	.	14	b 12		5	.	.	.	.
Pleasant Arm	S1	a 28	a 14	a 14	a 8	a 5	a 3	.	.	.
	S2	.	14	.	.	.	.	.	.	.
	S3	b 16	13	12	.	6	.	.	.	.
	S4	.	b 14	.	.	.	.	.	.	.
	S4-1	.	17	.	.	.	.	.	.	.
	S5	c 12	17	13	b 10	b 4	3	.	.	.

TABLE 16-2. Cold Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	44	16	a 88	a 96	b 109	b 141	c 25	d 70	a 23
Sandy Inlet	S1	.	.	a 17	a 5	a 13	a 10	a 9	d 15	.
	S2	.	.	b 31	25	b 24	b 9	b 14	31	.
Sandy Arm	S1	.	.	a 11	a 7	a 10	a 9	a 9	a 15	a 21
	S2	.	.	b 13	18	10	8	8	.	.
	S3	.	.	6	b 17	11	10	b 10	b 16	21
	S4	.	.	7	8	b 6	10	6	c 32	.
	S4-1	.	.	c 9	7	7	.	.	.	.
Pleasant Creek	S1	3	1	a 3	b 3	b 2	b 7	c 3	c 5	a 4
Pleasant Inlet	S1	.	.	a 4	a 8	a 9	a 6	a 8	c 4	a 3
	S2	.	.	4	8	b 5	8	b 8	3	4
Pleasant Arm	S1	.	.	a 6	a 8	a 10	a 8	a 8	a 6	a 4
	S2	.	.	b 5	8	10	8	8	.	5
	S3	.	.	5	b 9	10	8.	8	6	b 3
	S4	.	.	c 3	6	b 9	8	b 9	6	c .
	S4-1	.	.	3	6	6	.	5	.	3
	S5	.	.	6	c 6	8	8	c 8	b 5	3

TABLE 16-3. Cold Acidity (mg/liter $CaCO_3$), values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 4	a 5	a 14	a 3	b 1	a 2	a 3	a 3	1
Lower Pond	D1	a 2	a	a 5	a 3	a 3	a 3	a 5	a 3	.
	D2	b .	b 4	4	3	.	.	.	.	.
	D3	c 51	c 8	.	.	3	2	3	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 2	a 2	a 2	a 4	a 1	a 4	a 2	a 5
	D2	.	b 4	b 4	b 4	2	2	2	2
	D3	10	c 17	c 11	5	b 4	1	2	2

TABLE 17-1. Hot Acidity (mg/liter $CaCO_3$), values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 27	a 60	b 30	c 1	c 4	b 5	d 4	3	a 17
Lake Inlet	S1	a 19	a 55	b 8	c 7	4	b 4	.	.	a 14
	S2	30	54	.	3	c 20	3	.	.	18
Upper Lake	S1	a 22	a 15	a 12	a 7	a 4	a 6	.	.	a 4
	S2	22	32	11	.	.	.	.	.	5
	S3	b .	18	11	.	4	.	.	.	b .
	S4	29	b 17	.	b 8	.	.	.	.	9
	S4-1	27	.	7	c .	b .	.	.	.	18
	S5	c 25	c .	b .	1	2	5	.	.	6
Lower Lake	S1	a 12	a .	a 9	a 8	a 2	c 2	a 6	.	a 2
	S2	.	.	.	.	.	.	.	.	.
	S3	b 11	.	.	.	.	.	.	.	b 4
	S4	10	b .	.	.	.	.	.	.	4
	S4-1	8	.	.	b .	.	.	.	.	6
	S5	c .	10	8	.	.	.	.	.	4
	O	9	c .	b .	10	b 4	2	b 8	.	.
	B	6	.	c .	c 6	3	4	c 6	.	4

TABLE 17-1. Hot Acidity (mg/liter $CaCO_3$), values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a .	b . .	a 14	a 0	b 12	b 16	c 4	d 6	a 6
Lake Inlet	S1	a .	b .	a 12	a 5	a 11	b 10	c 3	d 7	a 8
	S2	.	.	b 11	5	b 11	12	3	6	7
	S3	.	.	6	7	.	.	2	.	.
Upper Lake	S1	a 12	a	a 9	a 12	a 15	a 11	a 9	c 12	a 3
	S2	.	.	b 7	12	15	9	11	.	.
	S3	b .	b .	7	15	15	9	13	12	4
	S4	-.-	.	c 7	b 8	b 14	10	b 9	11	.
	S4-1	.	.	6	8	8	.	4	.	4
	S5	.	.	6	c 7	9	10	c 5	10	4
Lower Lake	S1	a -.-	a .	a 7	a 12	a 15	a 9	a 11	a 26	a 5
	S2	b .	b .	b 8	13	15	9	13	.	.
	S3	.	.	7	b 15	15	9	9	6	b 6
	S4	-.-	.	c 6	11	b 15	9	b 11	6	c .
	S4-1	.	.	7	11	14	.	9	b .	.
	S5	.	.	6	10	14	11	8	7	5
	O	c .	.	6	c 11	9	11	c 3	c 7	5
	B	.	.	8	15	c 9	c 10	4	8	6

TABLE 17-2. Hot Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 67	c 57	c 65	b 48	.	38	67
Sandy Inlet	S1	a 15	a .	a 7	c 37	c 47	b .	.	.	.
	S2	b 45	31	b 9	.	.	50	.	.	.
Sandy Arm	S1	a 42	a 24	a 4	a 6	a 5	a 14	.	.	.
	S2	28	22	.	8	.	.	.	.	.
	S3	b 32	b 26	9	.	b 13	.	.	.	.
	S4	21	11	8	b 10	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c .	c 0	a 0	0	0	2
Pleasant Inlet	S1	a 11	a 13	a 9	b 12	b 4	a 3	.	.	.
	S2	.	13	b 11	.	c 5	.	.	.	.
Pleasant Arm	S1	a 11	a 16	a 11	a 8	a 6	a 4	.	.	.
	S2	.	16	.	.	.	.	.	.	.
	S3	b 12	17	9	.	5	.	.	.	.
	S4	.	b 15	.	.	.	.	.	.	.
	S4-1	.	13	.	.	.	.	.	.	.
	S5	c 6	9	15	b 6	b 4	2	.	.	.

TABLE 17-2. Hot Acidity (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2 Cruises 18	May 12 23	Jun 14-16 24	Jul 25-27 27	Aug 14-16 28	Sep 23 29	Oct 21-22 30	Nov 18-19 31	Dec 9 32
Sandy Creek	S1	45	.	a 100	b 110	b 126	b 169	c 28	d 79	a 25
Sandy Inlet	S1	.	.	a 18	a 12	a 19	a 10	a 10	d 20	.
	S2	.	.	b 33	28	b 28	b 13	b 17	37	.
Sandy Arm	S1	.	.	a 13	a 11	a 15	a 11	a 12	a 23	a 26
	S2	.	.	b 14	21	15	11	10	.	.
	S3	.	.	6	b 19	16	11	b 14	b 19	26
	S4	.	.	6	8	b 9	12	7	c 37	.
	S4-1	.	.	7	6	9	.	.	.	.
Pleasant Creek	S1	.	.	a 4	b 0	b 0	b 0	c 3	c 0	a 0
Pleasant Inlet	S1	.	.	a 5	a 11	a 14	a 9	a 10	c 0	a 0
	S2	.	.	5	12	b 8	11	b 11	0	0
Pleasant Arm	S1	.	.	a 7	a 13	a 15	a 10	a 10	a 7	a 5
	S2	.	.	b 8	13	15	10	11	.	6
	S3	.	.	7	b 18	15	10	11	8	b 4
	S4	.	.	c 5	9	b 13	10	b 9	8	c .
	S4-1	.	.	5	11	9	.	6	.	6
	S5	.	.	9	2	10	10	c 10	b 8	5

TABLE 17-3. Hot Acidity (mg/liter $CaCO_3$), values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a .	a 2	a 0	a 2	b 3	a 2	a 9	a 0	2
Lower Pond	D1	a .	a .	a 2	a 0	a 0	a 0	a 5	a 1	.
	D2	b .	b 0	2	2	.	.	.	.	.
	D3	c .	c 0	.	.	2	2	3	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a .	a 3	a 9	a 9	a 1	a 4	a 3	a 5
	D2	.	b 4	b 9	b 8	3	3	4	3
	D3	.	c 3	c 7	9	b 2	3	3	6

TABLE 18-1. Total Iron (mg/liter), values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates								
		Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a .	a 0.6	b 0.2	c ∠.1	c 0.2	b 1.0	d 1.3	0.4	a 1.8
Lake Inlet	S1	a .	a 0.6	b 0.2	c ∠.1	c 0.2	b 1.1	.	.	a 2.0
	S2	.	0.6	0.2	∠.1	0.1	1.1	.	.	2.6
Upper Lake	S1	a .	a 0.1	a 0.1	a ∠.1	a ∠.1	a ∠.1	.	.	a 1.1
	S2	.	∠.1	0.2	.	.	.	.	.	1.4
	S3	b .	∠.1	0.3	.	∠.1	.	.	.	b .
	S4	.	b ∠.1	.	b ∠.1	.	.	.	.	1.5
	S4-1	.	.1	0.2	c .	b .	.	.	.	.
	S5	c .	c 0.8	b 0.2	∠.1	0.4	1.4	.	.	1.5
Lower Lake	S1	a 0.1	a 0.2	a 0.2	a ∠.1	a 0.2	c ∠.1	a 0.5	.	a 1.1
	S2	.	0.2	.	.	.	.	.	.	.
	S3	b 0.1	0.1	.	.	.	.	.	.	b .
	S4	0.3	b 0.1	.	.	.	.	.	.	1.3
	S4-1	0.3	∠.1	.	b .	.	.	.	.	0.9
	S5	c .	.	0.1	.	.	.	.	.	1.5
	O	0.2	c 0.1	b 0.1	.	b 0.1	0.3	b 0.5	.	.
	B	0.1	0.2	c 4.3	c ∠.1	∠.1	0.5	c 1.0	.	1.4

TABLE 18-1. Total Iron (mg/liter), values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 0.3	b 1.6	a 0.2	a 0.1	b ∠.1	b 0.2	c 1.9	d 1.8	a 8.4
Lake Inlet	S1	a 0.3	b .	a 0.1	a ∠.1	a ∠.1	b 0.2	c 1.5	d 1.8	a 7.4
	S2	0.3	.	b 0.3	0.1	b 0.6	0.3	1.8	1.9	6.9
	S3	.	.	0.4	0.1	.	.	1.4	.	.
Upper Lake	S1	a .	a .	a 0.2	a 0.1	a .	a 0.1	a ∠.1	c 0.9	a 0.7
	S2	0.6	.	b 0.1	0.1	∠.1	0.1	∠.1	.	.
	S3	b .	b .	∠.1	0.1	∠.1	0.2	∠.1	.	0.8
	S4	0.5	.	c ∠.1	b 0.1	b 0.2	0.2	b ∠.1 0.1	1.0	.
	S4-1	.	.	∠.1	0.1	0.6	.		.	0.9
	S5	0.6	.	∠.1	c 0.2	1.6	0.1	c 0.3	1.0	.
Lower Lake	S1	a 0.5	a .	a 0.3	a .	a .	a 0.2	a ∠.1	a 0.2	a 0.8
	S2	b .	b .	b 0.3	.	.	0.1	∠.1	.	.
	S3	.	.	0.1	b 0.1	∠.1	0.1	∠.1	0.2	b 1.1
	S4	0.5	.	c 0.1	0.1	b ∠.1	0.2	b ∠.1	0.3	c .
	S4-1	.	.	0.1	0.1	∠.1	.	0.1	b .	.
	S5	0.2	.	0.1	.	0.1	.	0.7	0.4	0.8
	0	c 0.2	.	∠.1	c .	.	0.2	c 0.1	c 0.5	0.8
	B	∠.1	.	0.1	0.4	c 0.1	c 0.6	0.4	0.6	1.0

TABLE 18-2. Total Iron (mg/liter), values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	b .	.	c 1.4	c 1.3	b 3.5	.	3.1	2.1
Sandy Inlet	S1	.	b 0.1	a 0.5	c 0.1	c 0.6	b 3.4	.	.	.
	S2	.	0.4	b 0.5	.	.	3.7	.	.	.
Sandy Arm	S1	.	a ∠.1	a 0.1	a ∠.1	a 0.1	a 2.4	.	.	.
	S2	.	∠.1	.	.	.	.	.	.	.
	S3	.	b 0.1	0.4	.	b 0.1	.	.	.	.
	S4	.	.	0.8	b ∠.1	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c ∠.1	c ∠.1	a ∠.1	.	∠.1	0.3
Pleasant Inlet	S1	.	a ∠.1	a 0.5	b 0.1	b ∠.1	a .	.	.	.
	S2	.	∠.1	b 0.1	.	c ∠.1	.	.	.	.
Pleasant Arm	S1	.	a ∠.1	a 0.2	a ∠.1	a ∠.1	a 0.4	.	.	.
	S2	.	∠.1	.	.	.	.	.	.	.
	S3	.	∠.1	0.1	.	∠.1	.	.	.	.
	S4	.	b _.1	.	.	.	.	.	.	.
	S4-1	.	∠.1	.	.	.	.	.	.	.
	S5	.	0.1	0.1	b ∠.1	b 0.1	0.3	.	.	.

TABLE 18-2. Total Iron (mg/liter), values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	2.2	1.7	a 1.0	b 2.4	b 2.1	b 4.0	c 0.8	d 3.2	a 3.4
Sandy Inlet	S1	.	.	a 0.4	a 0.5	a 0.1	a 0.1	a 0.2	d 1.2	.
	S2	.	.	b 0.5	1.9	b 1.2	b 0.1	b 0.3	2.5	.
Sandy Arm	S1	.	.	a 0.2	a 0.1	a <.1	a 0.1	a 0.2	a 1.2	a 2.8
	S2	.	.	b 0.2	0.5	<.	0.3	0.3	.	.
	S3	.	.	0.2	b 0.5	≤.1	0.9	b 0.4	b 1.3	2.4
	S4	.	.	0.2	0.2	b 3.1	0.3	0.5	c 3.0	.
	S4-1	.	.	c 0.6	1.3	2.6	.	.	.	.
Pleasant Creek	S1	.1	0.9	a <.1	b 0.5	b 0.2	b 0.9	c 1.0	c 0.2	a 0.2
Pleasant Inlet	S1	.	.	a 0.1	a .	a <.1	a 0.8	a ≤.1	c 0.2	a 0.2
	S2	.	.	.	<.1	b <.1	<.1	b <.1	0.2	0.3
Pleasant Arm	S1	.	.	a 0.3	a 0.1	a .	a 0.6	a <.1	a 0.1	a 0.7
	S2	.	.	b 0.1	0.1	.	2.1	<.1	.	0.6
	S3	.	.	≤.1	≤.1	≤.1	0.7	<.1	0.2	b 2.0
	S4	.	.	c .	b .	b .1	0.7	b <.1	0.1	c .
	S4-1	.	.	0.1	.	0.1	.	.	.	1.0
	S5	.	.	0.1	c <.1	0.5	1.4	c <.1	b 0.1	0.9

TABLE 18-3. Total Iron (mg/liter), values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 0.1	a 0.8	a 0.3	a ∠.1	b ∠.1	a 0.4	a 0.6	a 0.1	0.8
Lower Pond	D1	a 0.2	a 0.2	a 0.2	a ∠.1	a 0.2	a 0.3	a 0.6	a 0.4	.
	D2	b .	b 0.2	0.5	∠.1	.	.	.	.	.
	D3	c .	c 1.8	.	.	∠.1	0.3	0.2	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 0.2	a 0.3	a 0.1	a 0.1	a 1.2	a 0.1	a 0.2	a 0.4
	D2	.	b 0.4	b 0.2	b 0.8	0.8	0.1	0.3	0.6
	D3	0.2	c 0.3	c 0.2	0.8	b 2.7	0.2	0.4	0.8

TABLE 19-1. Total Hardness (mg/liter $CaCO_3$), values for Tygart station sequence; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 18-26	Aug 1-4	Sep 10-11	Oct 22-23	Nov 19-20	Dec 18-19	Jan 28-29	Feb 25	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
River	S1	a 91	a 142	b 74	c 38	c 40	b 30	d 42	45	a 50
Lake Inlet	S1	a 104	a 138	b 60	c 51	c 40	b 26	.	.	a 45
	S2	93	138	63	44	48	31	.	.	56
Upper Lake	S1	a 42	a 44	a 53	a 55	a 70	a 26	.	.	a 37
	S2	43	44	50	.	.	.	.	.	45
	S3	b .	40	50	.	57	.	.	.	b .
	S4	34	b 52	.	b 53	.	.	.	.	44
	S4-1	35	38	53	c .	b .	.	.	.	45
	S5	c 34	c 32	b 55	45	52	35	.	.	41
Lower Lake	S1	a 43	a 43	a 54	a 60	a 44	c 59	a 46	.	a 24
	S2	39	40	.	.	.	.	.	.	.
	S3	b 47	40	.	.	.	.	.	.	b 29
	S4	36	b 36	.	.	.	.	.	.	29
	S4-1	36	40	.	b .	.	.	.	.	29
	S5	c .	66	79	.	.	.	.	.	27
	O	35	c 32	b 51	59	b 45	47	b 42	.	
	B	.	28	c 40	c 59	40	35	c 38	.	33

TABLE 19-1. Total Hardness (mg/liter $CaCO_3$), values for Tygart station sequence; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-15	Jul 25-26	Aug 14-15	Sep 23-24	Oct 21-22	Nov 19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
River	S1	a 45	b 22	a 58	a 50	b 46	b 83	c 29	d 42	a 30
Lake Inlet	S1	a 45	b .	a 56	a 44	a 45	b 71	c 29	d 45	a 30
	S2	41	.	b 44	44	b 44	73	33	42	30
	S3	.	.	31	47	.	.	29	.	.
Upper Lake	S1	a 41	a .	a 40	a 46	a 45	a 74	a 48	c 44	a 30
	S2	33	.	b 33	49	46	63	48	.	.
	S3	b .	b .	31	47	44	58	46	42	34
	S4	40	.	c 28	b 37	b 44	58	b 42	42	.
	S4-1	.	.	27	32	37	.	39	.	33
	S5	29	.	28	c 32	34	50	c 33	45	30
Lower Lake	S1	a 40	a .	a 32	a 39	a 46	a 52	a 51	a 46	a 31
	S2	b .	b .	b 34	42	46	50	50	.	.
	S3	.	.	30	b 48	46	54	49	44	b 31
	S4	25	.	c 30	36	b 46	56	b 54	42	c .
	S4-1	.	.	29	31	44	.	50	.	.
	S5	38	.	28	32	44	53	47	48	31
	O	c 31	.	26	c 29	39	45	c 42	42	31
	B	33	.	28	30	c 35	c 44	39	41	29

TABLE 19-2. Total Hardness (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; July through March 1966-1967; monthly selections from cruise series 1 through 16.

Station	Level	Dates Jul 20-21	Aug 5-9	Sep 10-11	Oct 21-23	Nov 19-20	Dec 18	Jan 29	Feb 25-26	Mar 11-12
		Cruises 1	2	4	7	9	11	13	15	16
Sandy Creek	S1	.	.	b 103	c 58	c 61	b 33	.	77	49
Sandy Inlet	S1	a 48	a 55	a 48	c 58	c 57	b 51	.	.	.
	S2	b 60	63	b 49	.	.	62	.	.	.
Sandy Arm	S1	a 48	a 55	a 53	a 60	a 53	a 27	.	.	.
	S2	49	56	.	.	.	.	.	.	.
	S3	b 35	58	49	61	b 73	.	.	.	.
	S4	40	b 77	.	b 52	.	.	.	.	.
Pleasant Creek	S1	.	.	.	c 234	c 194	a 124	151	118	122
Pleasant Inlet	S1	a 40	a 50	a 59	b 57	b 49	a 134	.	.	.
	S2	.	55	b 61	.	c 52	.	.	.	.
Pleasant Arm	S1	a 40	a 55	a 47	a 44	a 49	a 40	.	.	.
	S2	.	44	.	.	.	.	.	.	.
	S3	b 35	58	58	.	61	.	.	.	.
	S4	.	b 51	.	.	.	.	.	.	.
	S4-1	.	43	.	.	.	.	.	.	.
	S5	c 28	40	58	b 65	b 44	43	.	.	.

TABLE 19-2. Total Hardness (mg/liter $CaCO_3$), values for Sandy and Pleasant station sequences; April through December 1967; monthly selections from cruise series 18 through 32.

Station	Level	Dates Apr 1-2	May 12	Jun 14-16	Jul 25-27	Aug 14-16	Sep 23	Oct 21-22	Nov 18-19	Dec 9
		Cruises 18	23	24	27	28	29	30	31	32
Sandy Creek	S1	41	30	a 60	b 68	b 72	b 102	c 41	d 62	a 33
Sandy Inlet	S1	.	.	a 46	a 47	a 46	a 50	a 49	d 46	.
	S2	.	.	b 41	52	b 52	b 60	b 46	49	.
Sandy Arm	S1	.	.	a 48	a 47	a 44	a 56	a 51	a 45	a 35
	S2	.	.	b 34	50	45	66	46	.	.
	S3	.	.	31	b 48	48	57	b 60	b 46	35
	S4	.	.	30	36	b 44	60	41	c 50	.
	S4-1	.	.	c 28	33	36	.	.	.	.
Pleasant Creek	S1	151	49	a 165	b 194	b 141	b 107	c 152	c 175	a 133
Pleasant Inlet	S1	.	.	a 39	a 37	a 45	a 47	a 48	c 175	a 126
	S2	.	.	42	38	b 42	52	b 48	182	125
Pleasant Arm	S1	.	.	a 36	a 46	a 45	a 48	a 46	a 46	a 33
	S2	.	.	b 33	47	46	49	47	.	30
	S3	.	.	34	b 45	45	47	29	46	b 29
	S4	.	.	c 26	36	b 43	46	b 47	46	c .
	S4-1	.	.	25	31	38	.	46	.	32
	S5	.	.	10	c 30	21	47	c 48	b 46	31

TABLE 19-3. Total Hardness (mg/liter $CaCO_3$), values for Doe Pond station sequence; July through December 1966-1967; monthly selections from cruise series 1 through 32.

Station	Level	Dates Jul 21	Aug 9	Sep 25	Oct 21	Nov 19	Dec 19	Jan 28	Feb 25	Mar 12
		Cruises 1	2	5	7	9	11	13	15	16
Upper Pond	D1	a 31	a 47	a 88	a 51	b 36	a 35	a 197	a 82	41
Lower Pond	D1	a 34	a .	a 57	a 45	a 25	a 36	a 231	a 86	.
	D2	b .	b 65	42	46	.	.	.	.	.
	D3	c 68	c 54	.	.	36	40	214	.	.

Station	Level	Dates Apr 22	Jun 14	Jul 27	Aug 14	Sep 23	Oct 22	Nov 18	Dec 10
		Cruises 21	24	27	28	29	30	31	32
Lower Pond	D1	a 37	a 38	a 25	a 25	a 69	a 44	a 42	a 31
	D2	.	b 38	b 26	b 26	52	54	42	31
	D3	33	c 50	c 36	28	b 53	44	44	30

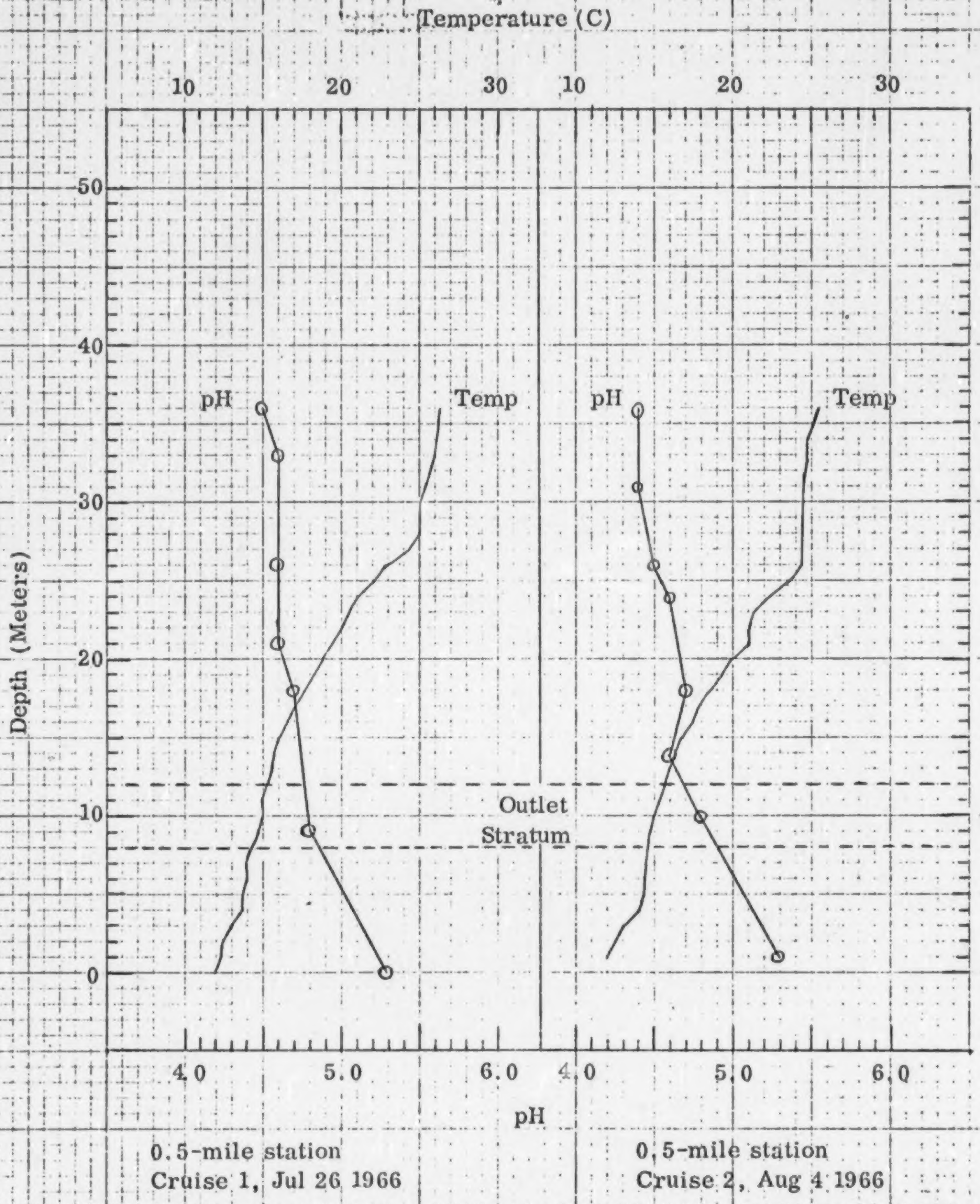


FIGURE 5. Temperature and pH profiles, Lower Lake station, Cruises 1 and 2.

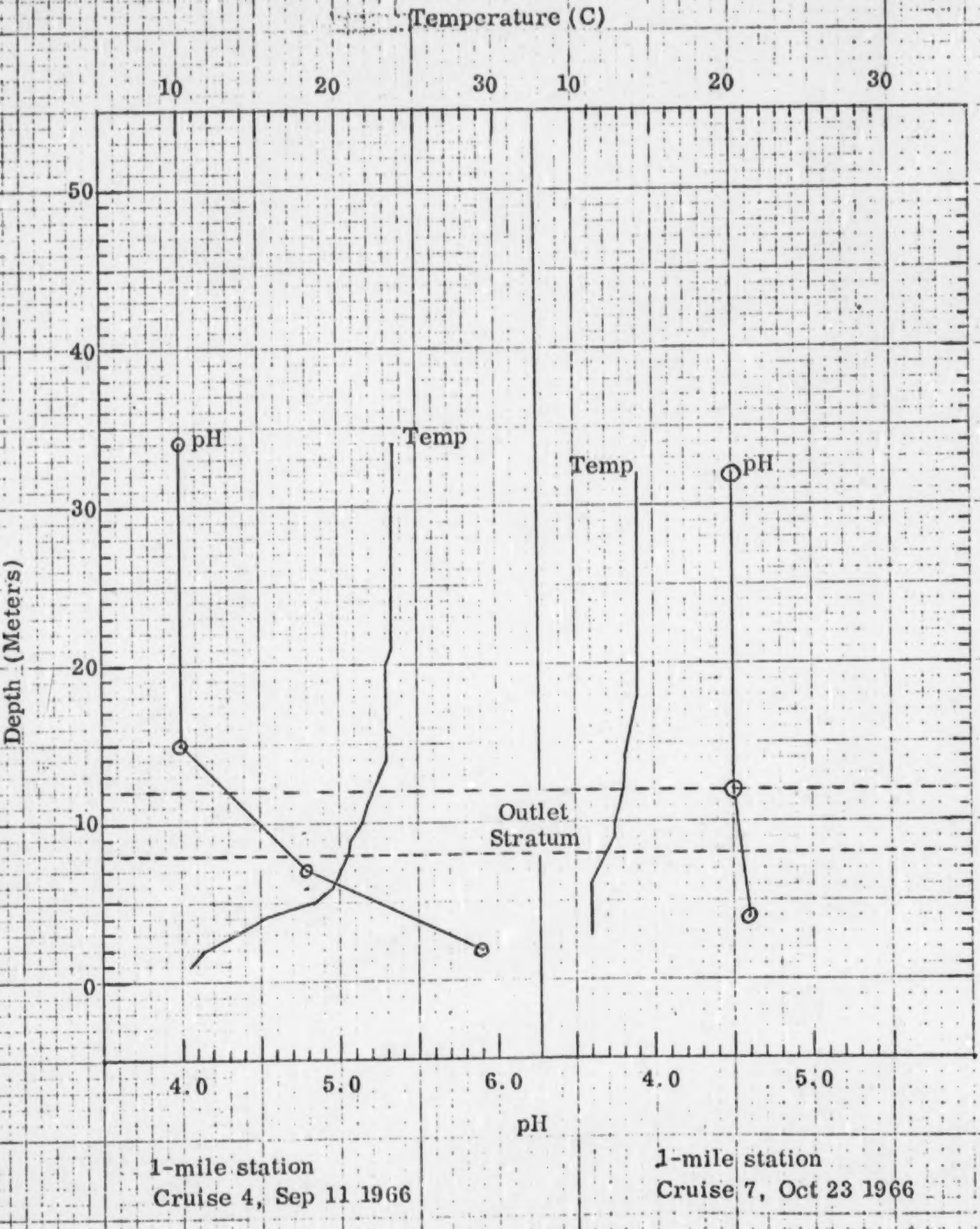


FIGURE 6. Temperature and pH profiles, Lower Lake station, Cruises 4 and 7.

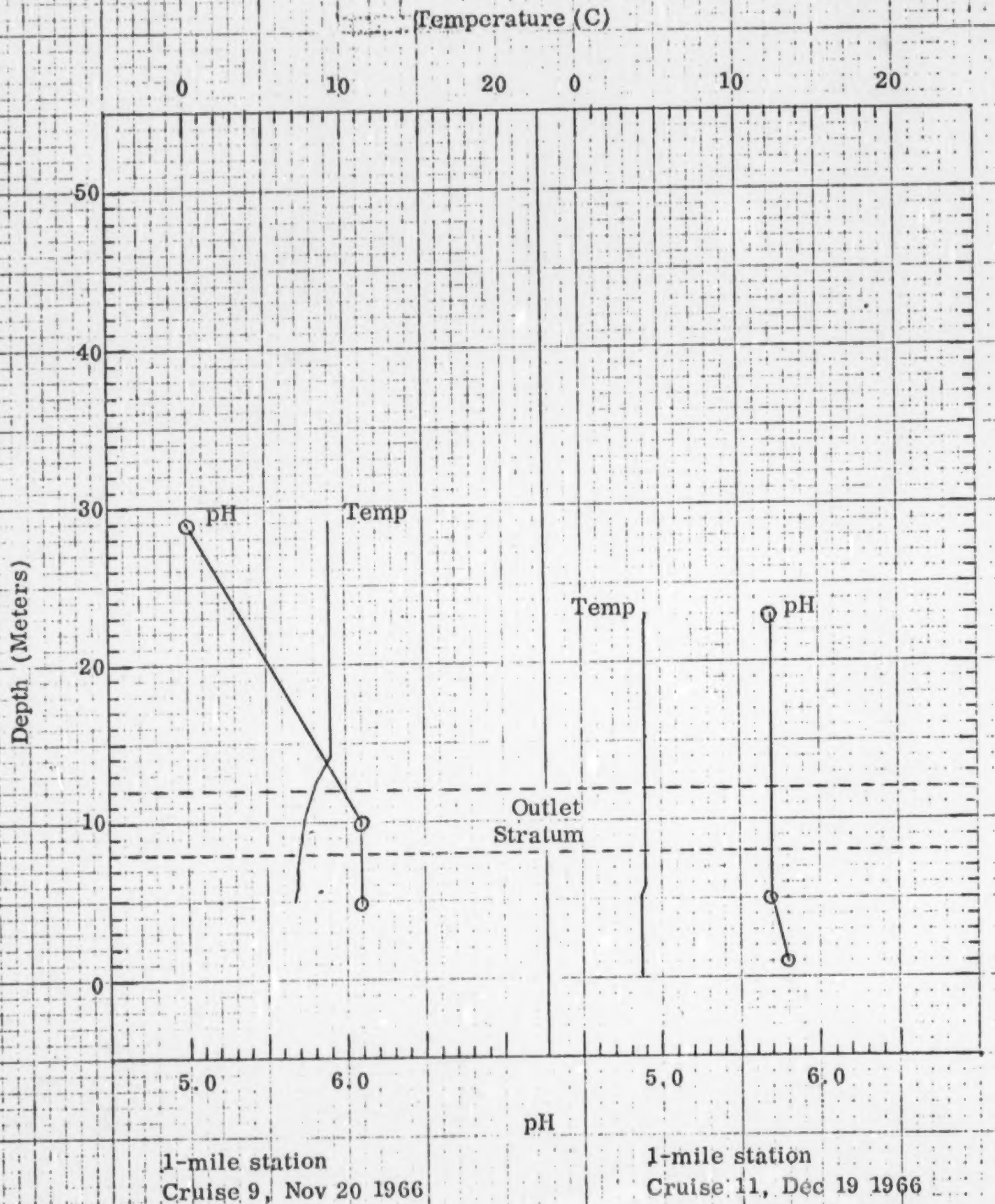


FIGURE 7. Temperature and pH profiles, Lower Lake station, Cruises 9 and 11.

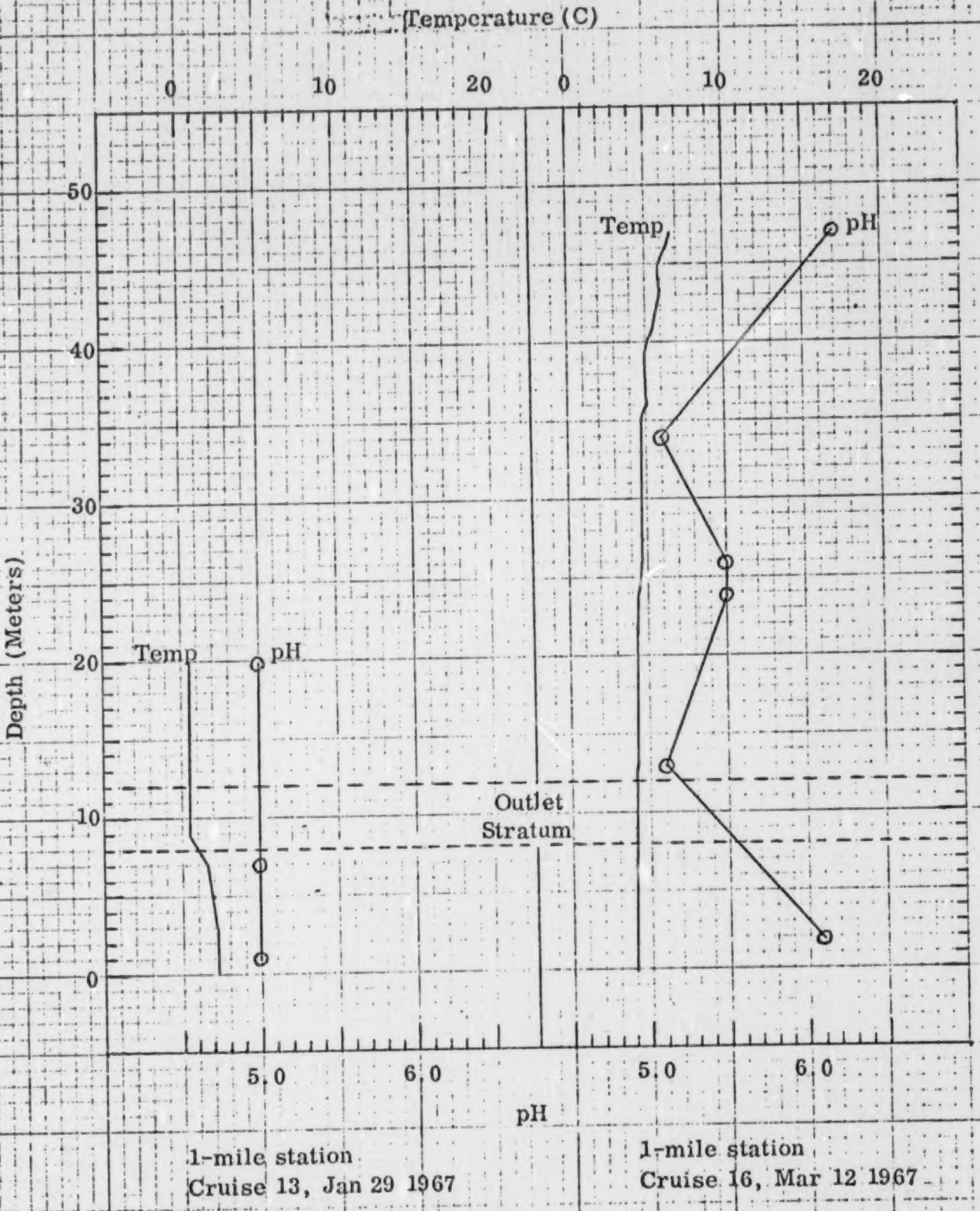


FIGURE 8. Temperature and pH profiles, Lower Lake station, Cruises 13 and 16.

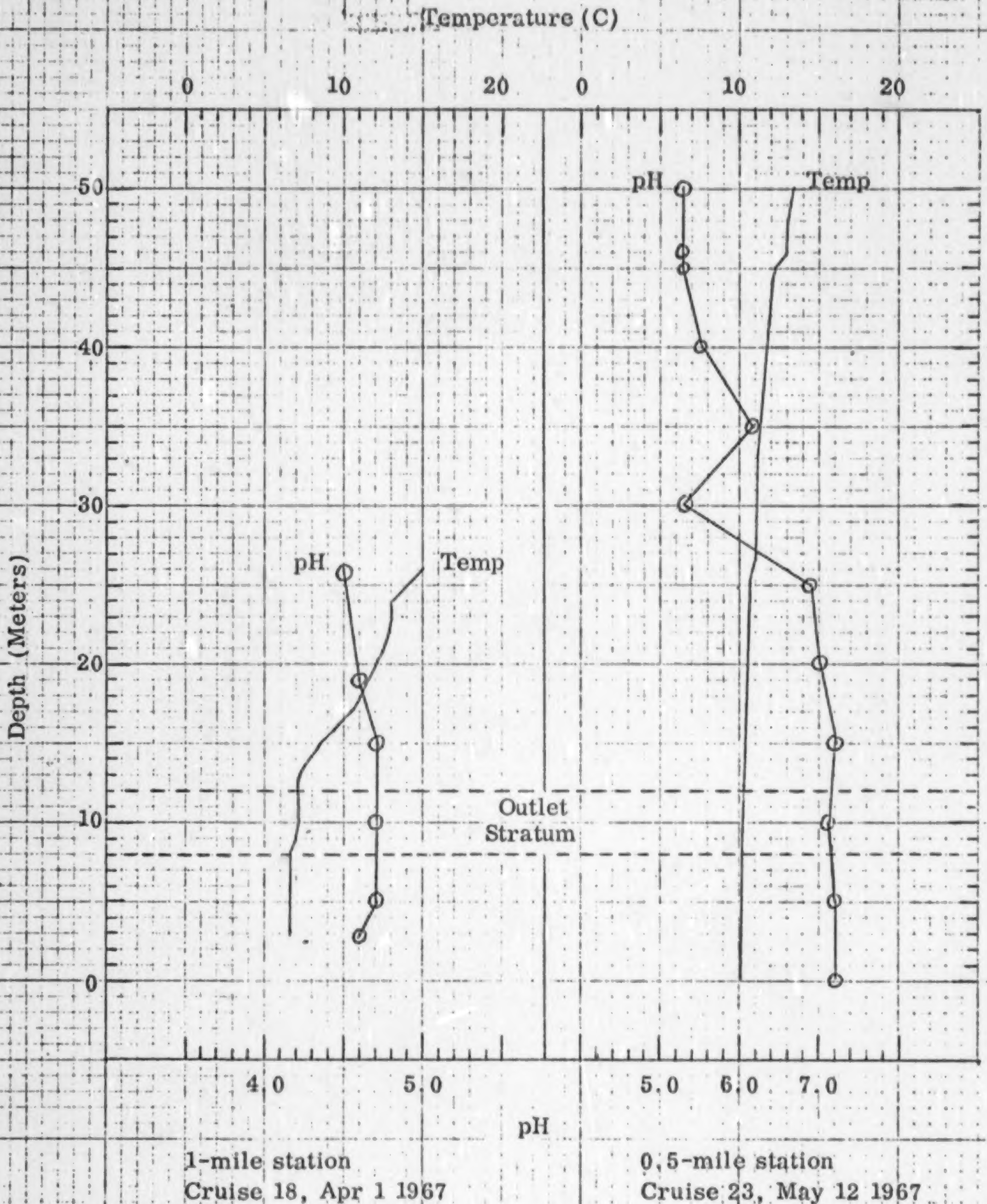


FIGURE 9. Temperature and pH profiles, Lower Lake stations, Cruises 18 and 23.

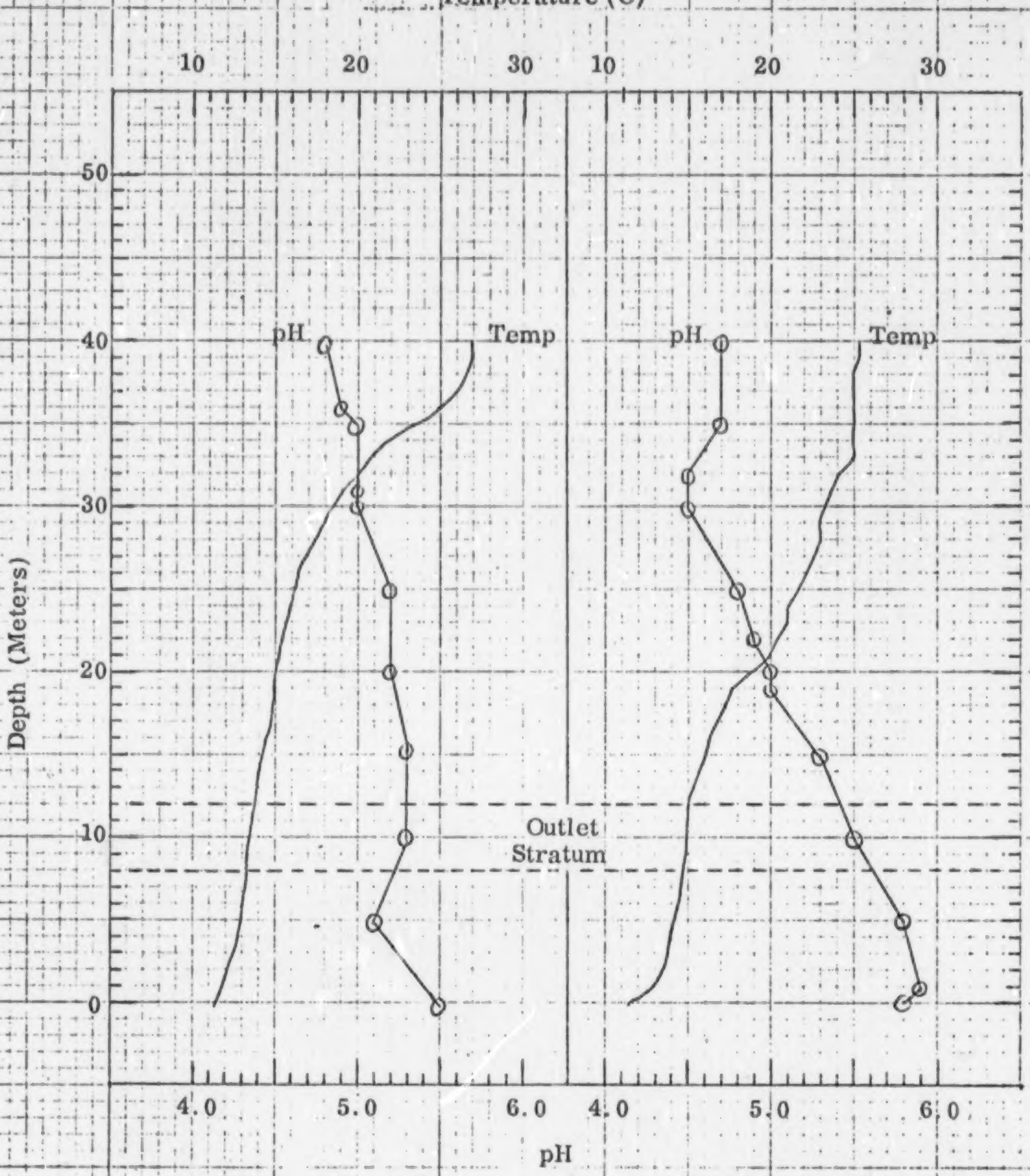


FIGURE 10. Temperature and pH profiles, Lower Lake station, Cruises 24 and 27.

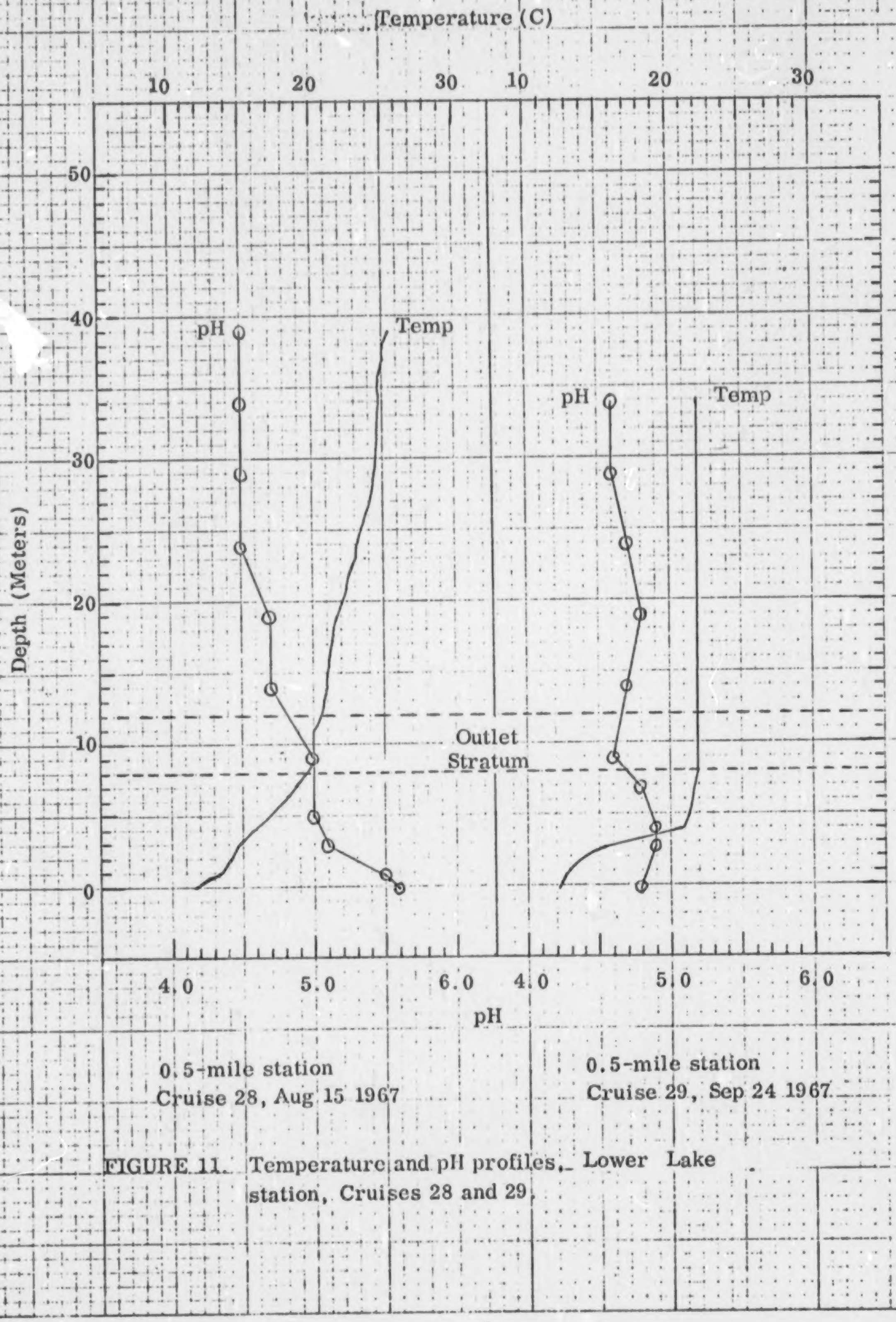


FIGURE 11. Temperature and pH profiles, Lower Lake station, Cruises 28 and 29.

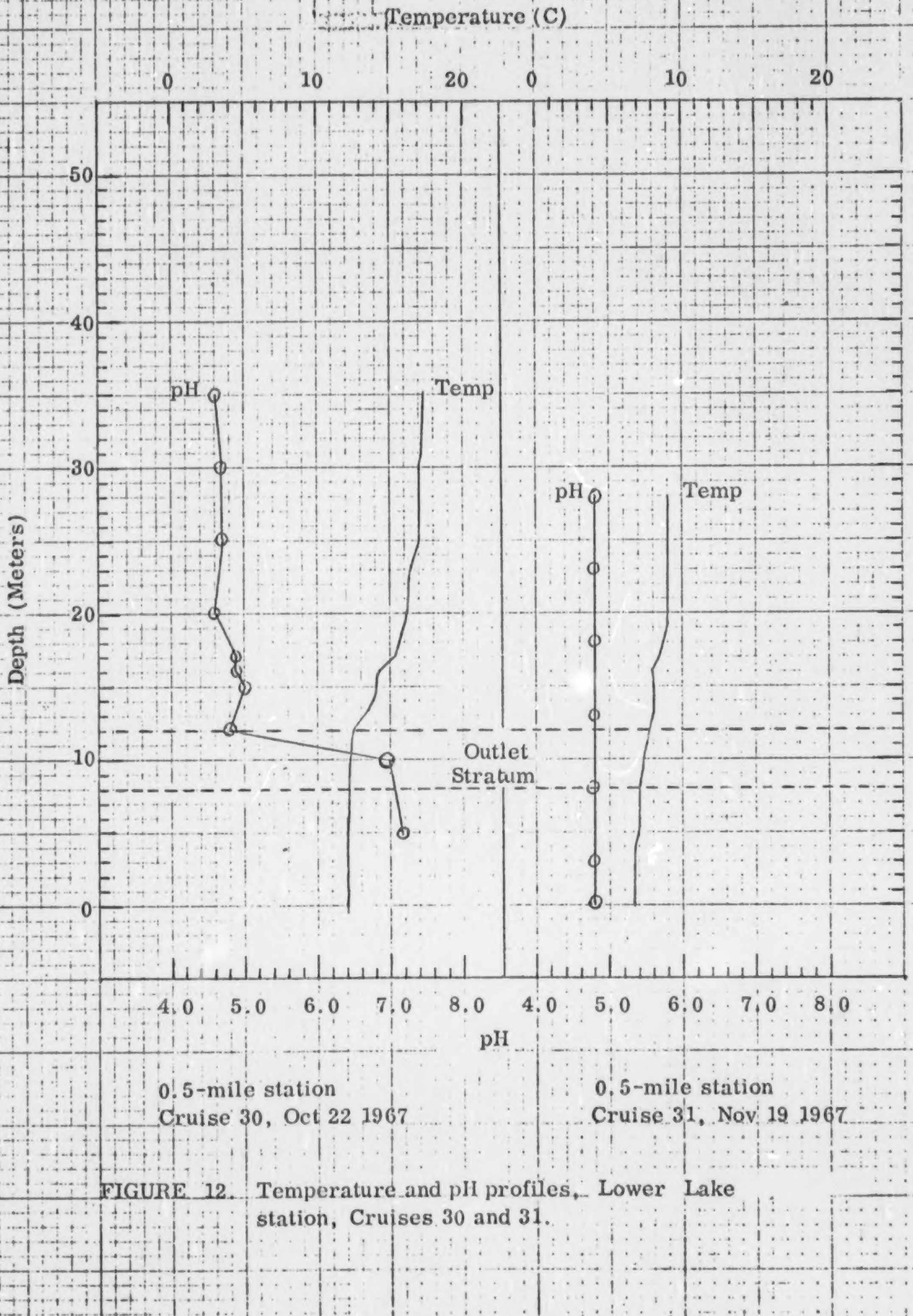
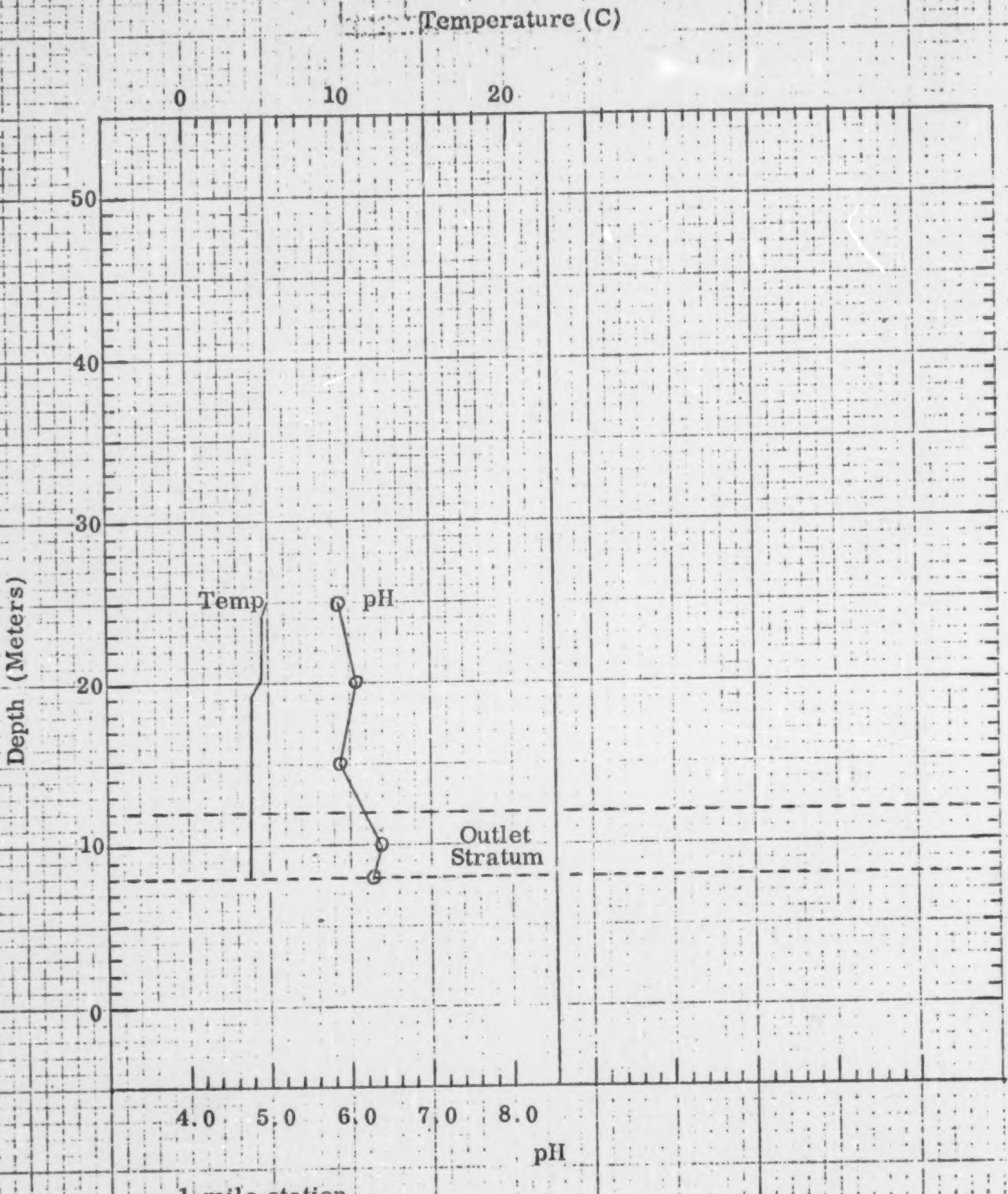


FIGURE 12. Temperature and pH profiles, Lower Lake station, Cruises 30 and 31.



1-mile station
Cruise 32, Dec 10 1967

FIGURE 13. Temperature and pH profiles, Lower Lake station, Cruise 32.

Data are presented for monthly selected cruises which illustrate the major seasonal changes in temperature and water chemistry over the 18 months of field work. Cruises which have been eliminated either yielded incomplete results or were not regarded as essential to the discussion of results.

Stations are grouped in Tables 12 through 19 as follows:

> Tygart sequence comprised of a River station (Tygart River, 12-mile or 9-mile sites), a Lake Inlet station (9-mile site), and Upper Lake station (5-mile site), and a Lower Lake station (1-mile or 0.5-mile sites).
>
> Sandy Arm sequence including Sandy Creek, Sandy Inlet in the upper arm below the creek mouth, and Sandy Arm at the point where it joins the main lake.
>
> Pleasant Arm sequence composed of Pleasant Creek, Pleasant Inlet in the upper arm below the creek mouth, and Pleasant Arm at the point of entry into the main lake.
>
> Locations of stations are given in Figure 3.

In Tables 10 through 19 the arrangement of data by "Levels" is based on proportional divisions of usable storage (volume above the minimum pool elevation of 1010 feet, 307.8 meters). Level S1 is the surface sampling point (0.5 meters depth) and proportionately is at the 100 percent usable storage level. Level S2 represents the sampling depth at the level of 75 percent of the usable storage. Level S3 is the sampling depth at the mid-point, 50 percent level, of usable storage. Level S4 refers to the sampling depth at the 25 percent usable storage level. Level S4-1 is at a point intermediate to levels S4 and S5. Level S5 is at the minimum pool elevation (307.8 meters) and represents the zero base-point of usable storage. Level O refers to the outlet stratum (elevation 302.2 to 306.1 meters which is approximately 2 meters below the base point of usable storage. Level B represents the bottom depth of the Lower Lake station (1-mile and 0.5-mile sites) at elevation 294 meters (964 feet).

This arrangement has been employed primarily as a means of condensing the tabular information. An advantage is that data at a given level are related by representing proportionately equivalent volumes even though they are not at the same depth. Because this treatment was made use of subsequent to sampling the relationship of usable storage levels to actual sampling positions is lacking in precision. Samples entered into the tables were selected on the basis of proximity to the estimated levels within usable storage. The actual locations of sampling positions in relation to usable storage levels are given in Tables 12-1 to 12-2 for the Tygart, Sandy, and Pleasant station sequences. Each sampling position given as a reference elevation is based on the elevation above the bottom contour of the 0.5-mile site. In Table 12-3 for the Doe Pond station sequence sampling positions are given as depths in meters. The different notation for Doe Pond was used because of its separation from Tygart Lake except during periods of flooding when the water level in Tygart Lake is above elevation 1094 feet.

The notations "a, b and c" are used in the tables to indicate thermal layers. The designation of thermal layers is made independently for each cruise within a given station sequence. In Cruise 1 for example (Table 13-1) the designation "a" indicates the extent of the epilimnion at the Lower Lake station and thermal continuity of the epilimnion is extrapolated back through the Upper Lake, Lake Inlet and River stations. Designations of "b" and "c" indicate metalimnion and hypolimnion respectively. Solid underline indicate the existence of a strong thermal discontinuity; broken underlines a weak discontinuity.

In Cruise 11 (Table 13-1) thermal regions are distinguished between stations. There are no thermal layers within stations. An intermediate situation is shown for Cruise 9 where the Lower Lake and Upper Lake stations show continuity between separable thermal layers designated "a" and "b". The colder water of the Lake Inlet and River stations constitutes a third thermal layer designated as "c". The lack of underlines indicates low thermal resistance to mixing.

Limnological Evaluation

The major factors related to the development of acidity gradients in Tygart Lake were found to be:

(1) hydrological characteristics including inflow, outflow and the operational interaction between inflow and outflow resulting in storage or drawdown.

(2) thermal relationships including the spring warming cycle, thermal stratification during the summer, the autumnal cooling cycle and the winter thermal minimum.

(3) water chemistry including the existing chemical stratification or its lack at the beginning of a seasonal period and the chemical quality of inflow.

This section on limnological evaluation is concerned with demonstrating the interactions between these factors which result in the development of graded patterns of acid distribution in Tygart Lake. Because these patterns are best illustrated by the results on pH, the major reference will be to that parameter.

Summer Pool

Hydrological information based on Corps of Engineers hydrographs indicates that inflows were at or near base flow level in 1966. The daily mean inflow was 225 c.f.s. from July 1 to August 19. In 1967 the mean inflow of 571 c.f.s. from June

16 to August 15 showed only slight improvement over the previous summer. In both years summer pool levels showed only minimum fluctuation (Table 12-1; Cruise 1 and 2, 1966; Cruises 24-28, 1967). Daily mean outflows for the periods above were 263 c.f.s. in 1966 and 595 c.f.s. in 1967.

Thermal stratification of the main lake is evident for the summer cruises 1 and 2 in 1966 and Cruises 24 through 28 in 1967 (Table 13-1 and Figures 5, 10 and 11). The approximate upper metalimnion boundary was at the 24 C isotherm in 1966 and 1967. The lower boundary was not well delineated, but appears to correspond to the 16 C isotherm in 1966 and the 15 C isotherm in 1967. The temperature profiles for the lower lake station (Figures 5, 10 and 11) show successively lower reference elevations for the upper and the lower metalimnion boundaries. This downward movement resulted from hypolimnion losses by outflow from the outlet stratum. Expansion of the epilimnion was primarily related to accumulation and mixing of the warm river inflow in the epilimnion. Surface heat loss also contributed as is suggested by the minor temperature regression in the epilimnion for both years.

In 1966 loss from the hypolimnion by outflow averaging 236 c.f.s. from July 26 to August 4 was estimated to be 4,211 acre-feet or about 5 percent of the usable storage. With a stable water level, compensation by inflow into the epilimnion would result in an extension in depth of the epilimnion and downward displacement of the metalimnion by 1 to 2 meters. In 1967 average outflow for the 41 day period between June 15 and July 26 was estimated as 423 c.f.s. The estimated loss by 34 percent of usable storage capacity at a pool elevation of 40 meters. In Figure 10, the temperature profiles show a 10 meter displacement of the 23.5 C isotherm corresponding to a volume decrease of about 34 percent of usable storage. That inflowing Tygart River water is largely stored in the epilimnion during the summer months is supported by the continuity of river and epilimnetic temperatures and the discontinuity with temperatures at the outlet level (Table 13-1).

The thermal discontinuity separating acid inflow at the surface from the deep outflow resulted in the graded pH patterns of summer Cruises 1 and 2 in 1966 and summer Cruises 24 through 27, 1967 (Table 15-1). Deterioriation of water quality in both 1966 and 1967 appears to have been closely related to the low inflow levels associated with deficient summer precipitation. The greatest extremes of pH, acidity and hardness for the Tygart River during the 18 months of investigation occurred in early August, Cruise 2 with a pH of 3.4, cold acidity of 59 mg/liter, hot acidity 60 mg/liter and total hardness of 142 mg/liter (Tables 15-1, 16-1, 17-1, and 19-1). The data in these tables for both 1966 and 1967 demonstrates an intensification of acidity gradients by storage and mixing of acid river water in the epilimnion. The lowest pH values and greatest acidities are in the surface layer. The 1966 Cruise 1 and 2 lower lake station data do not show pH changes in either the metalimnion or hypolimnion which would be indicative of acid density flow (Table 15-1). In 1967 the depth distribution and the thermal association of pH values in Cruises 24 and 27 do show relationships which suggest acid density interflow.

In the upper metalimnion Cruises 24 and 27 show a change from pH 5.0 to 4.5 at the 23 C isotherm (June 15 to July 26, Tables 13-1 and 15-1). This change is very well demonstrated by the negative heterograde inflection of the pH profile for July 26

(Figure 10). It is probable that this metalimnetic pH minimum originated by density flow. The Sandy Creek station sequence for Cruises 24 and 27 in Table 15-2 shows a series of pH values ranging from pH 3.2 to 4.3 associated with upper metalimnetic temperatures ranging from 21.0 to 24.4 C (Table 13-2). The arrangement with respect to higher pH values at other levels strongly suggests density interflow of extremely acid Sandy Creek water as a probable source of the heterograde pH minimum observed at the lower lake station.

An exception to the summer pool pattern of acid inflow occurred on July 25, 1967. In Table 15-1, Cruise 27, the river and lake inlet pH values above pH 7.0 contrast with their acidic neighbors. This inflow was characterized by moderate turbidity of 12 units (Table 10). It appears to have been associated with surface runoff from a local storm within the basin. The Corps of Engineers unit hydrographs for this date show precipitation of 0.3 of an inch and increase of about 300 c.f.s. inflow. Although temperature values were within the epilimnetic range (Table 13-1) this parcel of alkaline water probably entered the metalimnion as a turbid density current. Presumably the volume was too small to noticeably modify the acidic conditions observed in the metalimnion on August 15.

Transitional features representing the initial stages which lead into the autumnal circulation are evident in the data for mid-August 1967, Cruise 28. Table 13-1 indicates cooling of the Tygart River inflow. Although the surface temperatures of the lake stations remain high thermal regression associated with cooling is indicated in the epilimnion. The 22.8 C temperature of the Tygart River inflow suggests density interflow by its correspondence with similar values in the upper metalimnion of the lake. In Figure 11, Cruise 28, the lower lake temperature profile shows break down of the distinction between epilimnion and metalimnion. Vertical exchange established a uniform pH of 4.5 in the upper 25 meters. Tables 16-1 through 19-1 show similar uniformity of values for cold and hot acidity, total iron and total hardness. Removal of cold water from the hypolimnion was the principal factor responsible for weakening thermal stratification and enhancing the potential for vertical exchange in relation to secondary factors of surface cooling and density interflow. Evidence for the primary role of cold water loss is indicated by the 5 degree increase in temperature at 10 meters elevation in the outlet stratum. A lag effect of this "cold water drawdown" is suggested by the lack of uniform pH values in the upper lake station at a greater distance from the outlet.

Autumn-Winter Drawdown

The Corps of Engineers operational plan calls for gradual drawdown from the summer low-water regulation pool beginning about July 1 and continuing until the winter minimum pool is established about December 15. The winter pool level, except for flood storage, is maintained from mid-December to late March. Because of recreational use of the lake and low inflow rates in 1966 and again in 1967 drawdown during July and the first half of August was relatively small. Table 12-1 shows a pool elevation decrease of one meter for the August cruise in each year. For this report the drawdown period is conceived as beginning in the latter part of August and with incorporation of winter minimum pool levels extending to early February. Reference elevations in Table 12-1 indicate the first substantial decrease in elevation occurred in September with a decrease of 2 meters in 1966 and 5 meters in 1967.

Table 12-1, 1966-1967 shows substantial decrease in water level each month until the observed minimum of 20 meters was reached on January 29, 1967. A correspondingly low water level was recorded on February 25. Except for the increase in level related to a peak inflow in October, the pattern of declining pool levels was similar in 1967 from September to the last month of study, December.

The hydrological characteristics of the autumn-winter drawdown period are given in tabular form below:

Period	Inflow (c.f.s.)	Outflow (c.f.s.)	Difference (c.f.s.)	Storage (Acre-feet)
8/20 - 9/24/1966	219	583	—364	—721
9/25 - 11/20/1966	1,020	1,164	—144	—285
11/21 - 2/11/1967	2,256	2,493	—237	—454
8/16 - 9/24/1967	274	651	—376	—746
9/25 - 11/19/1967	1,172	1,386	—214	—715
11/20 - 12/10/1967	4,831	5,133	—302	—602

The results for temperature and water chemistry in Tables 13-1 through 19-1 show that chemical gradients are primarily the result of cold inflow into the warmer lake water. Underflow of Tygart River water was evident in Cruises 7 and 9, 1966 and Cruises 29 and 30, 1967. These underflows move along the reservoir bottom and eventually reach the outlet layer. This resulted in an extension of acid conditions from the summer months by direct passage from the inlet to the deep water outlet by passing storage in the upper levels. Cruises 9 in 1966 and 30 in 1967 show underflow of relatively alkaline water which bypasses overlying water of lower pH.

Spring Pool

The period from March through May overlaps the Corps of Engineers operational period of winter minimum pool, December 16 through March and the impoundment period for establishment of the summer low-water regulation pool, April to June 15. The spring pool period as defined in this report was characterized by extreme fluctuations in water level. It includes the major flood periods in March and May 1967 and the intervening drawdown in April. Table 12-1 shows pool elevations of 50 meters on March 11, 26 meters on April 1 and 50 meters on May 12.

The hydrological characteristics of the spring pool period are given in tabular form below.

Period	Inflow (c.f.s.)	Outflow (c.f.s.)	Difference (c.f.s.)	Storage (Acre-feet)
3/12 - 3/19/1967	8,731	6,748	1,982	3,934
3/20 - 4/1/1967	4,420	8,847	- 4,427	- 8,784
4/2 - 4/23/1967	2,835	1,825	1,010	2,004
4/24 - 5/12/1967	5,526	3,012	2,514	4,988

The major floods during the spring pool period essentially constituted a flushing of the entire reservoir with water of good chemical quality as is demonstrated for Cruises 16 and 23 in Tables 13-1 through 19-1. The surface runoff during these flood periods was characterized by pH values well above pH 6.0. During the intervening drawdown period, Cruise 18, the reduction of inflow was associated with renewed acid inflows. An important relationship evident in the water chemistry tables is a generally consistant relationship between water quality and surface runoff. Peak flows related to storm drainage usually produce inflows of good chemical quality. As inflow increasingly approaches base flow conditions the water becomes increasingly aicd.

Status of Fish Populations

Presentation of results for fish population studies is made in Tables 20 through 35. The results of previous studies summarized inTable 20 list 15 species recorded by previous investigations on Tygart Lake. The red ear sunfish recorded in the West Virginia Fish Division Report for 1960 is very likely in error. Presumably the reference is to the very similar pumpkinseed sunfish which was found to be relatively abundant at the time of the present study. In the same report the only catfish listed was the black bullhead. No other records of this species in Tygart Lake have been found. Probably the reference is to the similar and abundant brown bullhead.

Comparison of Table 21 listing species composition for 1966 and 1967 with the results of previous investigators shows a number of points of similarity. In 1966-1967 the listing of 13 species includes 9 species also represented in previous studies. The instances of non-matching names (with corrections for sunfish and bullhead species names) are species which were collected in very small numbers. It is likely that the black crappie is represented under the euphanism "crappies" in Table 20. In both current and previous studies the brown bullhead appears to be the dominant species present. Bluegill, pumpkinseed sunfish and largemouth bass (surprisingly) are represented by indications of substantial numbers in both current and previous studies. An apparent exception, the white sucker, is shown as being relatively abundant in the Pleasant Creek Arm in 1947-48 and 1960 (Table 20). Only one specimen was taken in the Pleasant Creek Arm during the two years of the present investigation. The only explanation that can be offered is that this species which is not acid tolerant may have taken refuge in Pleasant Creek during the periods of extreme acidity which were so prevalent during the summer and early autumn in 1966 and 1967. The indications of substantial numbers of white crappies in 1947-1948 indicates a subsequent decline in population numbers for following years. In view of the lack of forage species except in the Pleasant Creek Inlet its infrequent occurrence in 1966-1967 collections is not surprising.

Species composition of the acid polluted Arm and Lake sites compared with unpolluted Doe Pond shows major differences only with regard to the abundance of golden shiners and black crappies in Doe Pond and absence (golden shiners) or rarity (black crappie) in Tygart Lake and its tributary arms. With regard to Tygart Lake this may be interpreted as reflecting intolerance of the golden shiner to low pH and the lack of forage, golden shiners, for black crappies.

Table 24 gives catch rates by type of gear for the principal study areas. The Doe Pond catch rates may be used empirically for relative quantitative comparison. It is assumed that the Doe Pond catches represent low but fishable population levels. From this standpoint only the pumpkinseed sunfish and carp are represented at favorable catch levels in both Doe Pond and the principal lake study areas. The absence of largemouth bass in the listing for Doe Pond is not surprising since largemouth bass show selective indifference or avoidance of the gears used in this study. Sandy Arm which was the most acid area in the lake is easily the least favorable site with only sunfish and bullheads present. Reputation of the Pleasant Creek Arm as offering favorable fishing does not seem to be supported by the catch data. The lake and Pleasant Arm areas appear to be equally impoverished. This is not surprising in view of the finding of similar acid conditions in both the main lake and the Pleasant Creek Arm and inlet stations.

Tables 27, 28 and 29 are comparisons by size class and gear between management categories and principal study areas. With respect to gill nets Doe Pond surpassingly ranks first; the main lake and Pleasant Arm are about equal and together rank a poor second; and Sandy Arm ranks last. Wire hoop net catch rate totals show a similar discouraging result except that catch rates are at the same level in lake and arm stations. With respect to management categories for both wire hoop nets and gill nets Doe Pond shows generally favorable catch levels within each category. Forage fish are well represented in relation to game fish. With species combined into management categories the Pleasant Arm is shown as having a better catch rate for game fish than the other Tygart Lake study areas. Food fish representing principally brown bullheads is the dominant group in Tygart Lake.

Rotenone census results in Tables 30 through 35 are best compared with respect to weight values because the numerical densities are distorted by the large numbers of fingerlings. The 1966 Ford Island census results were poor because of shallow water and lack of cover at the site. Tables 30 and 31 list 12 species of which 6 were harvested in biomass densities greater than 1 kilogram/hectare. Comparison of results for the Pleasant Arm inlet between October 1966 and August 1967 show a shift from dominance by largemouth bass to dominance by bullheads between the two years. It is likely that this difference is seasonally related and does not reflect any real population changes. Carp are present in about the same proportion by weight in both years; which is fortuitous since the large biomass represents a single fish in each case. Among the sunfishes (Lepomis spp) the greater standing crop of bluegills over pumpkinseeds was surprising since the wire hoop net results showed exactly the reverse order. It is likely that this reflects preferential selectivity of the wire hoop nets for pumpkinseed sunfish. In other respects the species harvest generally supports the netting results.

Standing crop values for management categories in Tables 32 through 35 show approximately the same total biomass densities in Lick Run and the Pleasant Arm sites for both years.

Sandy Arm had an extremely low standing crop of 1.8 lbs/acre (2.09 kilograms/hectare). Pierce (1965) gives Rotenone sample results for Sutton Lake from four cove samples with a range in standing crop from 43 to 69 lbs/acre. Earlier samples 1962-1963 ranged from 4 lbs/acre to 136 lbs/acre. This is a relatively infertile body of water, however, the greater numbers of cove rotenone samples far exceed the standing crop range of 26 to 33 lbs/acre of the Pleasant Arm and Lick Run samples for Tygart Lake. The obvious conclusion is that pollution by acid mine drainage is responsible for the poor standing crops found in Tygart Lake since in other respects the reservoirs have similar drawdown regimes.

TABLE 20. Tygart Lake species composition in previous years (Seaman and Stephens 1948; Fish Division Report, W. Va. Conservation Commission 1960; Robinson 1961). Data expressed as percentages of total catch or total standing crop.

Family and species		1947-48[a] Gill net Pleasant Arm & Lake	1948[b] Creel census Location not given	1960[c] Rotenone census Pleasant Arm (2 acres)		1961[d] Creel census Pleasant Arm & Lake
		% No	% No	% No	% Wt	% No
Catostomidae						
Suckers						0.5
White sucker	*Catostomus commersoni*	39.2		44.6	75.5	
Red horse	*Moxostoma sp*	1.2				
Cyprinidae						
Carp	*Cyprinus carpio*	3.5		0.5	19.1	1.6
Golden shiner	*Notemigonus chrysoleucas*			2.6	0.5	
Bluntnose minnow	*Pimphales notatus*			few	<0.1	
Ictaluridae						
Bullhead	*Ictalurus spp*					51.0
Brown bullhead	*Ictalurus nebulosus*	28.6	47.0			
Black bullhead	*Ictalurus melas*			0.5	<0.1	
Channel catfish	*Ictalurus punctatus*	1.2	0.6			
Centrarchidae						
Crappie	*Pomoxis spp*					5.3
White crappie	*Pomoxis annularis*	7.6	43.4			
Largemouth bass	*Micropterus salmoides*	7.0	6.0	24.4	1.8	9.0
Rock bass	*Ambloplites rupestris*					
Sunfish	*Lepomis spp*					33.0
Bluegill sunfish	*Lepomis macrochirus*	2.3	3.0			
Red ear sunfish	*Lepomis microlophus*			26.4	3.0	

TABLE 20. (Continued)

Family and species		1947-48[a] Gill net Pleasant Arm & Lake	1948[b] Creel census Location not given	1960[c] Rotenone census Pleasant Arm (2 acres)		1961[d] Creel census Pleasant Arm & Lake
		% No	% No	% No	% Wt	% No
Percidae						
Johnny darter	*Etheostoma nigrum*			few	<0.1	
Blackside darter	*Percina maculata*			1.0	<0.1	
Total catch (number or weight		171	1005	193	80.5 lbs	2927

[a] Seaman and Stephens 1948. Gill nets, 300 ft x 6 ft, 2 inch and 3 inch mesh, 35 days of netting June 18 to August 29, 1947 and 27 days of netting July 13 to September 2, 1948. Principal netting in Pleasant Arm.

[b] Seaman and Stephens 1948. Creel census during April, May and June 1948. Number of days not indicated.

[c] Fish Division Report 1960. Census on September 30, 1960 at the mouth of Pleasant Creek (Arm). Maximum depth 18 ft.

[d] Robinson 1961. Creel census conducted at the Tygart Lake boat dock and Pleasant Creek Arm April 1 to September 4.

TABLE 21. Tygart Lake species composition expressed as numbers of fish collected in the study areas during 1966 and 1967.

Family and species	Collection method and collection area					
	Rotenone		Netting			Seining
	Arm & Lake		Arms	Lake	Doe Pond	Doe Pond[c]
	F[a]	SH[b]				
Catostomidae						
White sucker, Catostomus commersoni	0	0	1	0	0	0
Cyprinidae						
Carp, Cyprinus carpio	0	1	2	7	4	0
Golden shiner, Notemigonus chrysoleucas	0	0	0	0	39	0
Bluntnose munnow, Pimphales notatus	0	0	0	0	0	2
Ictaluridae						
Brown bullhead, Ictalurus nebulosus	13	9				0
Yellow bullhead, Ictalurus natalis	53	3	24	79	44	0
Centrarchidae						
Black crappie, Pomoxis nigromaculatus	0	1	4	6	45	3
White crappie, Pomoxis annularis	0	1	2	5	5	0
Largemouth bass, Micropterus salmoides	25	26	2	2	0	43
Rock bass, Ambloplites rupestris	0	0	0	1	0	0
Bluegill sunfish, Lepomis machrochirus	26	46	14	11	0	0
Pumpkinseed sunfish, Lepomis gibbosus	11	22	45	51	51	177
Green sunfish, Lepomis cyanellus	0	4	0	1	14	18
Hybrid sunfish, Lepomis sp x L sp	0	2	4	1	1	4
					1	0
Total number of fish	128	115	98	164	204	247
Number of units of effort[d]		2	78	112	29	1

[a] F - fingerling size (size ranges in Table 26).

[b] SH - subharvestable and harvestable sizes (size ranges in Table 26).

[c] Incomplete counts; fish are mostly fingerlings.

[d] Rotenone units of effort represent separate census efforts; netting units of effort represent the combined total of overnight sets for wire hoop nets, gill nets and trammel nets; the seining unit consists of 5 seine hauls made in one day.

TABLE 22. Distribution of fish collecting gear by areas and stations. Symbols (W, G, T) are used to indicate gear type in subsequent tables.

Areas	Gear	Total	Stations Inlet	 Middle	 Lower
Lake	Wire hoop net -W	81	30	34	17
	Gill net -G	23	8	10	5
	Trammel net -T	8	3	4	1
Pleasant Arm	Wire hoop net -W	27	11	8	8
	Gill net -G	8	3	3	2
	Trammel net -T	3	1	1	1
Sandy Arm	Wire hoop net -W	27	11	8	8
	Gill net -G	10	4	3	3
	Trammel net -T	3	1	1	1
Doe Pond	Wire hoop net -W	24			
	Gill net -G	4			
	Trammel net -T	1			
All areas combined	Wire hoop net -W	159			
	Gill net -G	45			
	Trammel net -T	15			

TABLE 23. Selectivity of collecting methods, based on a subjective appraisal of catch data in Tables 24 and 25.

++ and + represent degrees of positive selection
0 represents indifferent selection
- represents negative selection involving avoidance of the gear.

Appraisal omitted for species with insufficient catch information.

Management category	Collecting methods			
	Wire hoop net W	Gill net G	Trammel net T	Rotenone census
Game fish				
Black crappie	+	++	-	0
White crappie	+	++	-	0
Largemouth bass	-	0	-	+
Food fish				
Brown & yellow bullheads	0	++	0	+
Pan fish				
Bluegill sunfish	+	+	-	+
Pumpkinseed sunfish	++	+	-	+
Green sunfish				
Hybrid sunfish				
Rock bass				
Rough & forage fish				
Carp	-	+	++	+
White sucker				
Golden shiner	-	++	-	++

TABLE 24. Species catch as number/10 unit day by area and gear. W - wire hoop net; G - gill net; T - trammel net.

Species	Gear	Lake	Pleasant Arm	Sandy Arm	Doe Pond	Combined
Game fish						
Black crappie	W	0.5	0.7	0.0	14.0	2.6
	G	0.8	2.5	0.0	25.0	3.1
	T	0.0	0.0	0.0	0.0	0.0
White crappie	W	0.3	0.4	0.0	0.4	0.3
	G	0.9	1.2	0.0	10.0	1.6
	T	0.0	0.0	0.0	0.0	0.0
Largemouth bass	W	0.0	0.0	0.0	0.0	0.0
	G	0.9	2.5	0.0	0.0	0.9
	T	0.0	0.0	0.0	0.0	0.0
Food fish						
Brown & yellow bullheads	W	3.7	0.4	0.4	1.6	2.3
	G	21.0	18.0	8.0	100.0	24.0
	T	2.5	0.0	0.0	0.0	1.3
Pan fish						
Bluegill sunfish	W	0.9	2.2	1.5	17.0	3.6
	G	1.8	5.0	0.0	28.0	4.2
	T	0.0	0.0	0.0	0.0	0.0
Pumpkinseed sunfish	W	5.1	7.0	8.9	4.2	6.0
	G	3.8	1.2	1.0	10.0	3.3
	T	0.0	0.0	0.0	0.0	0.0
Green sunfish	W	0.1	0.0	0.0	0.4	0.1
	G	0.0	0.0	0.0	0.0	0.0
	T	0.0	0.0	0.0	0.0	0.0
Hybrid sunfish	W	0.1	0.4	0.8	0.4	0.3
	G	0.0	1.2	0.0	0.0	0.2
	T	0.0	0.0	0.0	0.0	0.0
Rock bass	W	0.1	0.0	0.0	0.0	0.1
	G	0.0	0.0	0.0	0.0	0.0
	T	0.0	0.0	0.0	0.0	0.0
Rough&forage fish						
Carp	W	0.0	0.0	0.0	0.0	0.0
	G	0.0	1.2	0.0	7.5	0.9
	T	8.8	3.3	0.0	10.0	6.0
White sucker	W	0.0	0.0	0.0	0.0	0.0
	G	0.0	1.2	0.0	0.0	0.2
	T	0.0	0.0	0.0	0.0	0.0
Golden shiner	W	0.0	0.0	0.0	0.0	0.0
	G	0.0	0.0	0.0	10.0	8.7
	T	0.0	0.0	0.0	0.0	0.0

TABLE 25. Species catch as grams/10 unit day by area and gear. W - wire hoop net; G - gill net; T - trammel net.

Species	Gear	Lake	Pleasant Arm	Sandy Arm	Doe Pond	Combined
Game fish						
Black crappie	W	49	56	0	750	150
	G	93	120	0	900	150
	T	0	0	0	0	0
White crappie	W	18	18	0	28	17
	G	26	75	0	480	69
	T	0	0	0	0	0
Largemouth bass	W	0	0	0	0	0
	G	180	340	0	0	150
	T	0	0	0	0	0
Food fish						
Brown & yellow bullheads	W	830	78	78	390	510
	G	4400	3900	2200	23000	5500
	T	1100	0	0	0	600
Pan fish						
Bluegill sunfish	W	30	93	140	260	95
	G	71	140	0	1000	510
	T	0	0	0	0	0
Pumpkinseed sunfish	W	250	440	560	780	310
	G	300	100	100	260	220
	T	0	0	0	0	0
Green sunfish	W	1.5	0	0	35	6.1
	G	0	0	0	0	0
	T	0	0	0	0	0
Hybrid sunfish	W	3.1	9.2	50	15	14
	G	0	32	0	0	5.8
	T	0	0	0	0	0
Rock bass	W	6.4	0	0	0	3.3
	G	0	0	0	0	0
	T	0	0	0	0	0
Rough&forage fish						
Carp	W	0	0	0	0	0
	G	0	430	0	7000	700
	T	25000	6000	0	9300	15000
White sucker	W	0	0	0	0	0
	G	0	840	0	0	150
	T	0	0	0	0	0
Golden shiner	W	0	0	0	0	0
	G	0	0	0	6700	600
	T	0	0	0	0	0

TABLE 26. Metric size class ranges and English equivalents by species for F - fingerling; S - subharvestable; and H - harvestable fish.

Species	Metric size class (total length in mm)			English equivalents (total length in inches)		
	F (max)	S (range)	H (min)	F (max)	S (range)	H (min)
Game fish						
Black crappie	100	101-180	181	3.94	4.00-7.09	7.12
White crappie	100	101-180	181	3.94	4.00-7.09	7.12
Largemouth bass	100	101-200	201	3.94	4.00-7.87	7.91
Food fish						
Brown bullhead	100	101-250	251	3.94	4.00-9.84	9.88
Yellow bullhead	100	101-200	201	3.94	4.00-7.87	7.91
Pan fish						
Bluegill sunfish	80	81-140	141	3.15	3.19-5.51	5.55
Pumpkinseed sunfish	80	81-140	141	3.15	3.19-5.51	5.55
Green sunfish	80	81-140	141	3.15	3.19-5.51	5.55
Sunfish hybrids	80	81-140	141	3.15	3.19-5.51	5.55
Rock bass	100	101-150	151	3.94	4.00-5.90	5.94
Rough & forage fish						
Carp	100	101-250	251	3.94	4.00-9.84	9.88
White sucker	100	101-250	251	3.94	4.00-9.84	9.88
Golden shiner	80	81-150	151	3.15	3.19-5.90	5.94

TABLE 27. Wire hoop net catch rates by number and weight for collection areas. F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Management category	Size class	Number/10 unit days				Kilograms/10 unit days			
		Lake	Pleasant Arm	Sandy Arm	Doe Pond	Lake	Pleasant Arm	Sandy Arm	Doe Pond
Game fish	F	0.3	0	0	0.4	0.01	0	0	<0.01
	S	0.1	0.4	0	11.2	0.01	0.02	0	0.48
	H	0.4	0.7	0	3.3	0.05	0.06	0	0.29
	Combined	0.8	1.1	0	14.9	0.07	0.08	0	0.77
Food fish	F	0	0	0	0	0	0	0	0
	S	1.4	0.4	0.4	1.2	0.23	0.08	0.08	0.28
	H	2.3	0	0	0.4	0.60	0	0	0.11
	Combined	3.7	0.4	0.4	1.6	0.83	0.08	0.08	0.39
Pan fish	F	0.2	0	0	6.2	<0.01	0	0	0.03
	S	3.9	5.9	5.6	14.6	0.13	0.22	0.26	0.30
	H	2.2	3.7	5.6	0.8	0.16	0.32	0.50	0.06
	Combined	6.3	9.6	11.2	21.6	0.29	0.54	0.76	0.39
Total	F	0.5	0	0	6.6	0.01	0	0	0.03
	S	5.4	6.7	6.0	27.0	0.37	0.32	0.34	1.06
	H	4.9	4.4	5.6	4.5	0.81	0.38	0.50	0.46
	Combined	10.8	11.1	11.6	38.1	1.19	0.70	0.84	1.55
Actual unit days		81	27	27	24	81	27	27	24

TABLE 28. Gill net catch rates by number and weight for collection areas. F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Management categories	Size class	Number/10 unit days				Kilograms/10 unit days			
		Lake	Pleasant Arm	Sandy Arm	Doe Pond	Lake	Pleasant Arm	Sandy Arm	Doe Pond
Game fish	F	0	0	0	0	0	0	0	0
	S	1.3	6.2	0	32.5	0.06	0.54	0	1.20
	H	1.3	0	0	2.5	0.23	0	0	0.10
	Combined	2.6	6.2	0	35.0	0.29	0.54	0	1.30
Food fish	F	0	0	0	0	0	0	0	0
	S	10.9	8.8	2.0	45.0	1.75	1.53	0.42	8.17
	H	9.6	8.8	6.0	55.0	2.66	2.34	1.78	15.04
	Combined	20.5	17.6	8.0	100.0	4.41	3.87	2.20	23.21
Pan fish	F	0	0	0	0	0	0	0	0
	S	1.3	6.2	0	32.5	0.31	0.18	0	0.96
	H	4.3	1.2	1.0	5.0	0.34	0.10	0.10	0.30
	Combined	5.6	7.4	1.0	37.5	0.65	0.28	0.10	1.26
Rough & forage fish	F	0	0	0	0	0	0	0	0
	S	0	0	0	10.0	0	0	0	0
	H	0	2.4	0	95.0	0	1.26	0	0
	Combined	0	2.4	0	105.0	0	1.26	0	0
Total	F	0	0	0	0	0	0	0	0
	S	13.5	21.2	2.0	120.0	2.12	2.25	0.42	10.33
	H	15.2	12.4	7.0	157.5	3.23	3.70	1.88	15.44
	Combined	28.7	33.6	9.0	277.5	5.35	5.95	2.30	25.77
Actual unit days		23	8	10	4	23	8	10	4

TABLE 29. Trammel net catch rates by number and weight for collection areas. F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Management category	Size class	Number/10 unit days Lake	Number/10 unit days Pleasant Arm	Number/10 unit days Sandy Arm	Number/10 unit days Doe Pond	Kilograms/10 unit days Lake	Kilograms/10 unit days Pleasant Arm	Kilograms/10 unit days Sandy Arm	Kilograms/10 unit days Doe Pond
Food fish	F	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0
	H	2.5	0	0	0	1.13	0	0	0
	Combined	2.5	0	0	0	1.13	0	0	0
Rough & forage fish	F	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0
	H	8.8	3.3	0	10.0	24.67	6.05	0	9.30
	Combined	8.8	3.3	0	10.0	24.67	6.05	0	9.30
Total	F	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0
	H	11.3	3.3	0	10.0	25.80	6.05	0	9.30
	Combined	11.3	3.3	0	10.0	25.80	6.05	0	9.30
Actual unit days		8	3	3	1	8	3	3	1

TABLE 30. Standing crop in metric units for species collected by rotenone census of two Tygart Lake coves, October 25, 1966.
F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Species	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Ford Island	Kilogram/hectare Pleasant Arm inlet	Kilogram/hectare Ford Island
Game fish					
Black crappie	F	0	0	0	0
	S	0	0	0	0
	H	2.5	0	0.33	0
	Combined	2.5	0	0.33	0
White crappie	F	0	0	0	0
	S	2.5	0	0.20	0
	H	0	0	0	0
	Combined	2.5	0	0.20	0
Largemouth bass	F	59.3	1.6	0.49	0.01
	S	19.8	3.3	1.44	0.16
	H	39.5	0	7.49	0
	Combined	118.6	4.9	9.42	0.17
Food fish					
Brown bullhead	F	32.1	0	0.16	0
	S	22.2	0	1.36	0
	H	0	0	0	0
	Combined	54.3	0	1.52	0
Yellow bullhead	F	130.9	0	0.57	0
	S	4.9	0	0.31	0
	H	2.5	0	0.33	0
	Combined	138.3	0	1.21	0

TABLE 30. continued. Standing crop in metric units for species collected by rotenone census of two Tygart Lake coves, October 25, 1966.
F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Species	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Ford Island	Kilograms/hectare Pleasant Arm inlet	Kilograms/hectare Ford Island
Pan fish					
Bluegill sunfish	F	64.2	0	0.22	0
	S	71.7	0	2.23	0
	H	42.0	0	3.96	0
	Combined	177.9	0	6.41	0
Pumpkinseed sunfish	F	24.7	1.6	0.10	0.01
	S	44.5	1.6	1.11	0.07
	H	7.4	0	0.46	0
	Combined	76.6	3.2	1.67	0.08
Green sunfish	F	0	0	0	0
	S	7.4	0	0.07	0
	H	2.5	0	0.14	0
	Combined	9.9	0	0.21	0
Hybrid sunfish	F	0	0	0	0
	S	2.5	0	0.07	0
	H	2.5	0	0.23	0
	Combined	5.0	0	0.30	0
Rough fish					
Carp	F	0	0	0	0
	S	0	0	0	0
	H	2.5	0	7.00	0
	Combined	2.5	0	7.00	0

TABLE 31. Standing crop in metric units for species collected by rotenone census of three Tygart Lake coves, August 7-9, 1967.

F - Fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Species	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Lick Run inlet	Number/hectare Sandy Arm inlet	Kilograms/hectare Pleasant Arm inlet	Kilograms/hectare Lick Run inlet	Kilograms/hectare Sandy Arm inlet
Game fish							
Black crappie	F	0	0	0	0	0	0
	S	2.1	0	0	0.04	0	0
	H	0	0	0	0	0	0
	Combined	2.1	0	0	0.04	0	0
White crappie	F	0	0	0	0	0	0
	S	2.1	0	0	0.08	0	0
	H	0	0	0	0	0	0
	Combined	2.1	0	0	0.08	0	0
Largemouth bass	F	226.7	30.4	16.7	0.42	0.06	0.06
	S	22.9	7.3	4.8	1.24	0.32	0.13
	H	0	0	0	0	0	0
	Combined	249.6	37.7	21.5	1.66	0.38	0.19
Food fish							
Brown and Yellow bullheads	F	1,899.0	323.4	2.4	1.73	0.20	0.03
	S	25.0	85.6	2.4	1.68	9.54	0.24
	H	16.6	66.7	2.4	4.36	18.09	0.75
	Combined	1,940.6	475.7	7.2	7.77	27.84	1.02
Pan Fish							
Bluegill sunfish	F	104.0	16.0	2.4	0.63	0.09	0.02
	S	195.5	97.2	35.7	4.07	2.24	0.86
	H	12.5	13.0	0	0.98	1.00	0
	Combined	312.0	126.2	38.1	5.68	3.27	0.88

TABLE 31 continued. Standing crop in metric units for species collected by rotenone census of three Tygart Lake coves, August 7-9, 1967.
F - Fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Species	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Lick Run inlet	Number/hectare Sandy Arm inlet	Kilograms/hectare Pleasant Arm inlet	Kilograms/hectare Lick Run inlet	Kilograms/hectare Sandy Arm inlet
Pumpkinseed sunfish	F	6.2	0	0	0.05	0	0
	S	29.1	29.0	0	0.85	1.01	0
	H	0	11.6	0	0	0.80	0
	Combined	35.3	40.6	0	0.90	1.81	0
Green sunfish	F	0	0	0	0	0	0
	S	14.6	1.4	0	0.21	0.02	0
	H	0	0	0	0	0	0
	Combined	14.6	1.4	0	0.21	0.02	0
Sunfish spp.	F	241.3	0	0	0.11	0	0
	S	0	0	0	0	0	0
	H	0	0	0	0	0	0
	Combined	241.3	0	0	0.11	0	0
Rockbass	F	0	0	0	0	0	0
	S	0	1.4	0	0	0.04	0
	H	0	0	0	0	0	0
	Combined	0	1.4	0	0	0.04	0

TABLE 31 continued. Standing crop in metric units for species collected by rotenone census of three Tygart Lake coves, August 7-9, 1967.

F - Fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Species	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Lick Run inlet	Number/hectare Sandy Arm inlet	Kilograms/hectare Pleasant Arm inlet	Kilograms/hectare Lick Run inlet	Kilograms/hectare Sandy Arm inlet
Rough fish							
Carp	F	0	0	0	0	0	0
	S	0	0	0	0	0	0
	H	2.1	0	0	9.67	0	0
	Combined	2.1	0	0	9.67	0	0
Johnny darter	F	160.2	0	0	0.07	0	0
	S	0	0	0	0	0	0
	H	0	0	0	0	0	0
	Combined	160.2	0	0	0.07	0	0
Bluntnose minnow	F	25.0	0	0	0.01	0	0
	S	0	0	0	0	0	0
	H	0	0	0	0	0	0
	Combined	25.0	0	0	0.01	0	0

TABLE 32. Standing crop in metric units for management categories collected by rotenone census of two Tygart Lake coves, October 25, 1966. F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Management category	Size class	Number/hectare		Kilograms/hectare	
		Pleasant Arm inlet	Ford Island	Pleasant Arm inlet	Ford Island
Game fish	F	59.3	1.6	0.49	0.01
	S	22.2	3.3	1.64	0.16
	H	42.0	0	7.82	0
	Combined	123.5	4.9	9.95	0.17
Food fish	F	163.0		0.73	
	S	27.2		1.67	
	H	2.5		0.33	
	Combined	197.7		2.72	
Pan fish	F	89.0	1.6	0.33	0.01
	S	126.0	1.6	3.48	0.07
	H	54.4	0	4.80	0
	Combined	269.4	3.2	8.61	0.08
Rough fish	F	0		0	
	S	0		0	
	H	2.5		7.00	
	Combined	2.5		7.00	
	Total	588.1	8.1	28.28	0.25

TABLE 33. Standing crop in metric units for management categories collected by rotenone census of three Tygart Lake coves, August 7-9, 1967.
F - fingerling; S - subharvestable; H - harvestable (size ranges in Table 26).

Management Category	Size class	Number/hectare Pleasant Arm inlet	Number/hectare Lick Run inlet	Number/hectare Sandy Arm inlet	Kilograms/hectare Pleasant Arm inlet	Kilograms/hectare Lick Run inlet	Kilograms/hectare Sandy Arm inlet
Game fish	F	226.7	30.4	16.7	0.42	0.06	0.06
	S	27.0	7.2	4.8	1.37	0.32	0.13
	H	0	0	0	0	0	0
	Combined	253.8	37.6	21.5	1.79	0.38	0.19
Food fish	F	1899.0	323.4	2.4	1.73	0.20	0.03
	S	25.0	85.6	2.4	1.68	9.54	0.24
	H	16.6	66.7	2.4	4.36	18.09	0.75
	Combined	1940.6	475.7	7.2	7.77	27.84	1.02
Pan fish	F	351.5	16.0	2.4	0.78	0.09	0.02
	S	239.2	129.0	35.7	5.12	3.31	0.86
	H	12.5	24.6	0	0.98	1.74	0
	Combined	603.2	169.6	38.1	6.88	5.14	0.88
Rough fish	F	185.1	0	0	0.07	0	0
	S	0	0	0	0	0	0
	H	2.1	0	0	9.67	0	0
	Combined	187.2	0	0	9.74	0	0
	Total	2984.8	682.9	66.8	26.19	33.36	2.09

TABLE 34. Standing crop in English units for species and management categories collected by rotenone census of two Tygart Lake coves, October 25, 1966.

	Number/ acre		Pounds / acre	
Species	Pleasant Arm inlet	Ford Island	Pleasant Arm inlet	Ford Island
Game fish				
Black crappie	1		0.30	
White crappie	1		0.18	
Largemouth bass	48	2.0	8.40	0.15
Food fish				
Brown and Yellow bullheads	78		2.43	
Pan fish				
Bluegill sunfish	72		5.72	
Pumpkinseed sunfish	31	1.3	1.49	0.07
Green sunfish	4		0.19	
Hybrid sunfish	2		0.27	
Rough fish				
Carp	1		6.25	
Management category				
Game fish	50	2.0	8.88	0.15
Food fish	78		2.43	
Pan fish	109	1.3	7.63	0.07
Rough fish	1		6.25	
Total	238	3.3	25.19	0.22

TABLE 35. Standing crop in English units for species and management categories collected by rotenone census of three Tygart Lake coves, August 7-9, 1967.

Species	Number/acre			Pounds/acre		
	Pleasant Arm inlet	Lick Run inlet	Sandy Arm inlet	Pleasant Arm inlet	Lick Run inlet	Sandy Arm inlet
Game fish						
Black crappie	0.8			0.04		
White crappie	0.8			0.07		
Largemouth bass	100.0	15.3	8.6	1.44	0.34	0.17
Food fish						
Brown and Yellow bullheads	777.2	192.9	2.9	6.72	24.96	0.90
Pan fish						
Bluegill sunfish	125.0	51.2	15.2	4.91	2.93	0.77
Pumpkinseed sunfish	14.2	16.5		0.77	1.62	
Green sunfish	5.8	0.6		0.18	0.02	
Sunfish spp.	96.3			0.09		
Rockbass		0.6			0.04	
Rough fish						
Carp	0.8			8.37		
Johnny darter	64.1			0.06		
Bluntnose minnow	10.0			0.01		
Management category						
Game fish	101.6	15.3	8.6	1.55	0.34	0.17
Food fish	777.2	192.9	2.9	6.72	24.96	0.90
Pan fish	241.3	68.9	15.2	5.95	4.61	0.77
Rough fish	74.9			8.44		
Total	1195.0	277.1	26.7	22.66	29.91	1.84

LITERATURE CITED

APHA, AWWA AND WPCF. 1965. Standard methods for the examination of water and wastewater. 12th ed. Amer. Public Health Assoc., New York. 769 p.

Corps of Engineers. 1961. Report upon second sedimentation survey of Tygart River Reservoir, Monongahela River Basin, West Virginia. U. S. Army Corps of Engineers, Pittsburgh District, Pittsburgh, Pennsylvania. (mimeographed, 13 p. 29 plates).

Corps of Engineers. 1969. Water resources development in West Virginia. U. S. Army Corps of Engineers, Ohio River Division, Cincinnati, Ohio. 69 p.

Friel, E. A., Wilmoth, B. M., Ward, P. E., and J. W. Wark. 1967. Water resources of the Monongahela River Basin, West Virginia. U. S. Geological Survey and Div. of Water Resources, West Virginia Dept. Natural Resources, Charleston, West Virginia. 118 p.

FWPCA. 1969a. Stream pollution by coal mine drainage in Appalachia. Fed. Water Pollution Control Administr. Revised 1969. Cincinnati, Ohio. 261 p.

FWPCA. 1969b. Inventory of coal mine drainage sources, selected areas, Upper Ohio River Basin. Work document No. 32. Fed. Water Pollution Control Administr., Cincinnati, Ohio. 104 p.

Grimas, Ulf. 1962. The Effect of increased water level fluctuation upon the bottom fauna in Lake Blasjon, Northern Sweden. Institute of Freshwater Research Report No. 44. 14-41 p.

Henry, Edgar N. 1967. A report on recommended water quality criteria and uses relative to interstate waters with Pennsylvania-Maryland. Div. Water Resources, West Virginia Dept. Natural Resources, Charleston, West Virginia. (mimeographed, in 4 parts).

Hill, Ronald D. 1969. Reclamation and revegetation of 640 acres of surface mines, Elkins, West Virginia. Fed. Water Pollution Control Administr., Cincinnati, Ohio. (mimeographed, 45 p.).

Hulsey, A. H. 1957. Effects of a fall and winter drawdown on a flood control lake. S. E. Assoc. of Game and Fish Comm. Proc. 10th Ann. Conf. 285-289 p.

Jenkins, Robert M. 1968. The influence of some environmental factors on standing crop and harvest of fishes in U. S. reservoirs, p. 298-321. In Reservoir Fishery Resources Symp., Athens, Gerogia, 5-7 April, 1967.

Kinney, Edward C. 1962. The potential importance of reservoirs. Part II: Types of reservoirs. West Virginia Conserv. May, 1962: 18-23. .

Menendez, Raymond. 1966. Cheat Lake acid mixing effect. D. J. Project F-11-R-4, Job No. 5. Game and Fish Div., West Virginia Dept. Natural Resources, Charleston, West Virginia. (mimeographed, 8 p.).

Robinson, David W. and H. R. Preston. 1961. Tygart Reservoir creel census. D. J. Project F-10-R-2, Job No. 2. Game and Fish Div., West Virginia Dept. Natural Resources, Charleston, West Virginia. (mimeographed, 5 p.).

Seaman, E. A. and R. F. Stephans. 1948. Fish depths distribution studies of Tygart Reservoir, West Virginia. Presented at 78th Annual Meeting, Amer. Fish. Soc. September, 1948. Atlantic City, New Jersey. (mimeographed, 18 p.).

Swingle, H. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Alabama Polytechnic Institute. Agricultural Experiment Station Bulletin No. 274.

Tyurin, P. 1961. Effect of the water level regime in reservoirs on the formation of fish stocks. Invest Gas Nauchn Issled Inst. Osernogo I Rechnogo Rylun Knoz 50: 395-410.